LIBRARY
Brigham Young University

Call No. 666
Am35t
V.19

TP
785
.AC6
V. 19

C. H. Lawson
1917

TRANSACTIONS

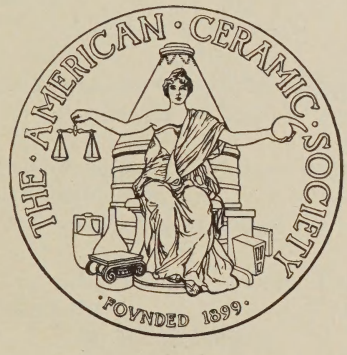
OF THE

American Ceramic Society

VOLUME XIX

Containing the Papers Read at the Meeting Held at New York, N. Y., March 5th, 6th, 7th and 8th, 1917, Together with Supplementary Discussions and Other Matters.

ARTHUR S. WATTS, *Editor*



This Society is not, as an organization, responsible for the statements of facts or opinions expressed in these papers and discussions.

PUBLISHED FOR THE SOCIETY, UNDER THE SUPERVISION OF
EDWARD ORTON, JR., *Secretary*,
R. K. HURSH, *Treasurer*.
ARTHUR S. WATTS, *Editor*,
CONSTITUTING THE PUBLICATION COMMITTEE.

COPYRIGHT, 1917, BY EDWARD ORTON, JR., *Secretary*, COLUMBUS, OHIO.
ALL RIGHTS RESERVED.

PRESS OF
THE F. J. HEER PRINTING CO.
COLUMBUS, OHIO

BRIGHAM YOUNG UNIVERSITY
LIBRARY
PROVO, UTAH

CONTENTS.

	PAGE
Officers of the Society for the Year 1917-1918	9
Membership of the Society	10
Rules of the Society	37
Publications	46
Annual Report of the Board of Trustees	48
Report of the Beaver Section	56
Report of the Ohio State University Student Branch	57
Report of New York State Student Branch	58
Report of University of Illinois Student Branch	60
Report of Iowa State College Student Branch	62
In Memoriam	64
1. Presidential Address By Lawrence E. Barringer.	69
2. Volume Changes of Some Commercial Silica Bricks on Heating By Donald W. Ross.	83
3. Study of Effect of Variation of Pressure in the Forming of Dust Pressed Tile By Forrest K. Pence.	94
4. The Advantages of Clay Storage and the Description of a Successful Installation By F. H. Riddle.	102
5. Apatite, a Substitute for Bone Ash By N. B. Davis.	125
6. Notes On the Use of Sulphuric Acid in the Sedimentation of Kaolins By H. G. Schurecht.	130
7. Enameled Surfaces Under the Microscope By Emerson P. Poste.	146
8. Glass Sands By Chas. R. Fettke.	160

PAGE

9. The Latent Heats of Fusion of Lime and Magnesia..... 195
By E. W. Washburn.

10. Principles Controlling the Formation and Removal of Bubbles in Molten Glass..... 201
By Raymond M. Howe.

11. Note on Pinholing and Peeling on Terra Cotta..... 209
By Hewitt Wilson.

12. Heat Balance of a Continuous Tunnel Kiln..... 216
By Carl B. Harrop.

13. The Burning Properties of Some American Refractory Clays.. 248
By H. G. Schurecht.

14. The Magnesite Deposits of the Grenville District, Quebec.... 254
By M. E. Wilson.

15. A New Principle in Temperature Measurement..... 260
By W. C. Harter.

16. The Effect of the Size of Grog in Fire Clay Borders..... 268
By F. A. Kirkpatrick.

17. The Practical Application of Bristol Glazes Compounded on the Eutectic Basis 301
By Arthur S. Watts.

18. The Relation Between the Fusion Point and the Composition of Refractory Clays..... 303
By R. J. Montgomery and C. E. Fulton.

19. A Study of Three Component Normative Systems in Raw Lead Glazes 312
By Wm. G. Whitford.

20. Glass Tank Furnace Operation..... 331
By R. L. Fink.

21. American Clays for Floating Enamels..... 339
By J. B. Shaw.

PAGE

22. Notes on the Manufacture of Promenade Tile..... 361
By Marion W. Blair.

23. Discussion — In What Chemical Condition Does Manganese Exist in Glass When Used as a Decolorizer, and What Factors of Furnace Conditions Affect It?..... 370

24. Chrome-Tin Colors at Cone 9..... 378
By R. H. Minton.

25. Notes on the Production of Special Refractories — Marquardt Porcelain and Magnesium Aluminate..... 397
By F. H. Riddle.

26. The Effect of Variation in Pressure and Moisture Upon the Forming of Dust Pressed Tile..... 409
By F. W. Walker, Jr., and E. G. Kerr.

27. The Effect of Porosity of the Body and the Moisture Content of the Glaze in the Application of Mat Glazes..... 428
By F. S. Hunt.

28. A Study of the Physical and Chemical Properties of Three Compounds of Lead and Their Use in Raw Lead Glazes.. 442
By F. A. Morgan.

29. The Development of Ceramic Decorative Processes..... 449
By Frederick H. Rhead.

30. A Deformation Study of $MgO - Al_2O_3 - SiO_2$ Mixtures..... 453
By Arthur S. Watts.

31. A Deformation Study of $BaO - Al_2O_3 - SiO_2$ Mixtures..... 457
By Arthur S. Watts.

32. The Relation of Salt to Clay in the Purification of Clays..... 460
By H. G. Schurecht.

33. Notes on Flow of Clay Through Hollow Ware Dies..... 479
By Geo. D. Morris.

34. Wet Clay Elevator..... 484
By Geo. D. Morris.

PAGE

35. Relation of Fusing Point of Ash to Availability of Coal for Burning Ceramic Wares 488
By Richard R. Hice.

36. Modified Load Test for Fire Brick 498
By J. B. Shaw.

37. Paving Brick from Blast Furnace Slag 507
By J. B. Shaw.

38. An Instrument for Measuring Plasticity 523
By Warren E. Emley.

39. Discussion — The Fine Grinding of Refractory Materials 534

40. Humidity, Its Control and Relation to the Drying of Clay Wares 508
By W. H. Denmead.

41. Measurement of the Time of Set of Calcined Gypsum 573
By Warren E. Emley.

42. Recent Improvements of Methods of Terra Cotta Mold Making 585
By R. B. Keeler.

43. Causes for the Failure of Terra Cotta in the Wall 593
By R. L. Clare.

44. The Crawling of Mat Glazes 597
By Chas. F. Binns and Mary E. Saunders.

45. The Properties of Some American Bond Clays 601
By A. V. Bleininger and G. A. Loomis.

46. Note on the Temperature, Porosity, Volume Changes of Some Porcelain Bodies 636
By Geo. A. Loomis.

47. The Control of Fusibility in Fritted Glazes 642
By Homer F. Staley and R. J. Riley.

PAGE

48. Note on Over-glaze Colors at Cones 6-7 653
By Hewitt Wilson.

49. The Cost of Raw Lead Glazes 659
By Homer F. Staley and L. C. Hewitt.

50. Investigation of the Ternary System Willemite-Tephroite, Soda Glass 674
By H. C. Arnold.

OFFICERS

For the Year 1917-1918

President

GEORGE H. BROWN.....New Brunswick, N. J.

Vice President

C. EDWARD JACKSON.....Wheeling, W. Va.

Secretary

EDWARD ORTON, JR.....Columbus, Ohio

Treasurer

R. K. HURSH.....Urbana, Ill.

BOARD OF TRUSTEES (1917-1918)

The four above named officers and

HOMER F. STALEY, term expires 1918.
A. F. HOTTINGER, term expires 1919.
E. T. MONTGOMERY, term expires 1920.

EX-PRESIDENTS AND WHERE MEETINGS HAVE BEEN HELD

HERBERT A. WHEELER	1899-1900	Columbus, Ohio
KARL LANGENBECK	1900-1901	Detroit, Mich.
CHARLES F. BINNS	1901-1902	Old Point Comfort, Va.
ERNEST MAYER	1902-1903	Cleveland, Ohio
EDWARD C. STOVER	1903-1904	Boston, Mass.
FRANCIS W. WALKER	1904-1905	Cincinnati, Ohio
WILLIAM D. GATES	1905-1906	Birmingham, Ala.
WILLARD D. RICHARDSON	1906-1907	Philadelphia, Pa.
STANLEY G. BURT	1907-1908	St. Louis, Mo.
ALBERT V. BLEININGER	1908-1909	Columbus, Ohio
ROSS C. PURDY	1909-1910	Pittsburg, Pa.
HEINRICH RIES	1910-1911	Trenton, N. J.
CHARLES WEELANS	1911-1912	Chicago, Ill.
ARTHUR S. WATTS	1912-1913	Washington, D. C.
ELLIS LOVEJOY	1913-1914	Wheeling, W. Va.
CULLEN W. PARMELEE	1914-1915	Detroit, Mich.
RICHARD R. HICE	1915-1916	Cleveland, Ohio
LAWRENCE E. BARRINGER	1916-1917	New York, N. Y.

HONORARY MEMBERS

DEUTSCHER VEREIN FÜR TON-, ZEMENT- UND KALKINDUSTRIE, Hon. Albert March, President, Dreysestrasse 4, Berlin, N. W., Germany.

ENGLISH CERAMIC SOCIETY, Mr. A. Leese, President, 81 Vivian Road, Fenton, Stoke-on-Trent, England.

STORER, MRS. MARIA LONGWORTH (Mrs. Bellamy Storer), Founder of the Rookwood Pottery Company, Cincinnati, Ohio.

BRANNER, JOHN C., PH. D., President, Leland Stanford Junior University.

OFFICERS OF LOCAL SECTIONS AND STUDENT BRANCHES

Beaver Local Section

F. W. Walker, Jr., *Chairman,*
Herford Hope, *Secretary,*
Ernest Mayer, *Councilor.*

Ohio State University Student Branch

P. D. Helser, *Chairman,*
M. R. Scott, *Secretary,*
Arthur S. Watts, *Councilor.*

New York State Student Branch

George Crawford, *Chairman.*
Robert Sherwood, *Secretary.*
Charles F. Binns, *Councilor.*

University of Illinois Student Branch

J. W. Wright, *Chairman,*
J. L. Crawford, *Secretary,*
R. K. Hursh, *Councilor.*

Iowa State College Student Branch

Bert Sweely, *Chairman,*
Lowell Hewitt, *Secretary,*
Homer F. Staley, *Councilor.*

FOREIGN MEMBERS

BROCKBANK, CLARENCE J., Thorold, Ontario, Canada.	Manager, Electric Furnace Plant, The Exolon Company
HEUBACH, A. R., Schorndorf, near Stuttgart, Germany.	Technical Manager, Porzellanfabrik, Bauer and Pfeiffer
KEELE, JOSEPH, Ottawa, Canada	Department of Mines, Mines Branch
KNOTE, JOHN M., M.Sc., Sault Ste Marie, Ont., Canada	Metallurgical Engineer to Mines Department, Lake Superior Corporation
KOERNER, J. A., PH.D., Coburg, Germany.	Editor, Sprechsaal
PUKALL, WILHELM, PH. D., 4 Bergstrasse, Bunzlau, Germany.	Director, Royal School of Ceramics
SINGER, FELIX G., DR.ING., Selb, Bavaria.	Chemist, Ph. Rosenthal Porcelain Factory
TAKAHASHI, KAKUICHIRO, CR.E., Hodogaya, near Yokohama, Japan	General Superintendent, Nippon Garas Kogyo Kaiska
WORCESTER, WOLSEY G., Calgary, Alberta, Canada	
ZIMMER, WILLIAM H., PH.D., Waldershof, im Fichtelgebirge, Bavaria, Germany.	Manager, Johann Haviland Porcelain Factory

RESIDENT MEMBERS

AUBREY, ARTHUR J., 285 Lora Ave., Youngstown, Ohio	Assistant General Superintendent, Bessemer Limestone Company
BARRINGER, L. E., E.M. (in Cer.) Schnectady, N. Y.	Engineer of Insulations, General Electric Company
BATES, P. H., B.Sc., 40th and Butler Sts., Pittsburgh, Pa.	Chemist, United States Bureau of Standards
BEECHER, MILTON F., Worcester, Mass.	Refractory Engineer, Research Laboratories Norton Company
BINNS, CHARLES F., M.Sc., Alfred, N. Y.	Director, New York State School of Clay-Working and Ceramics
BLEININGER, ALBERT V., B.Sc., 40th and Butler Sts., Pittsburgh, Penna.	United States Bureau of Standards
BROWN, GEORGE H., CR.E., New Brunswick, N. J.	Director, Department of Ceramics, Rutgers College
BURT, STANLEY G., 2349 Ashland Ave., Cincinnati, Ohio	Rookwood Pottery Company

CANNAN, WILLIAM, JR., 303 Tennyson Ave., Syracuse, N. Y.	Pottery Salesman
*COULTER, L. B., E.M., (in Cer.) Niagara Falls, N. Y.	Ceramic Engineer, Carborundum Company
COWAN, R. GUY, B.Sc., (in Cer.) 1360 Nicholson St., Cleveland, Ohio	The Cowan Pottery Studio
*DENMEAD, WALTER ANGUS, CR.E., Schenectady, N. Y.	Assistant Engineer of Insulations, General Electric Company
EMLEY, WARREN E., V.S., CH.E., 40th and Butler Sts., Pittsburgh Pa.	Assistant Chemist, United States Bureau of Standards
FARNHAM, DWIGHT T., A.B., Third National Bank Bldg., St. Louis, Mo.	Industrial Engineer
FICKES, WALTER M., E.M., (in Cer.) Niagara Falls, N. Y.	Aluminum Company of America
FISKE, J. PARKER B., B.S., Arena Building, New York City	Fiske and Company, Incorporated
FRINK, ROBERT L., Lancaster, Ohio	President, Frink Laboratories
FULTON, CLARENCE EDWARD, CR.E., Creighton, Pa.	Pittsburg Plate Glass Company
GALPIN, SIDNEY L., A.B., A.M., Ames, Iowa	Department of Mining and Geology, Iowa State College
GARVE, T. WALTER, M.E., 1108 Dennison Ave., Columbus, Ohio	Ceramic Supply and Construction Company
GATES, ELLIS D., The People's Gas Bldg., Chicago, Ill.	American Terro Cotta and Ceramic Company
GATES, WILLIAM D., A.M., People's Gas Bldg., Chicago, Ill.	President and General Manager, American Terra Cotta and Ceramic Company
GEIJSBEEK, SAMUEL, 604 Blake-McFall Bldg., Portland, Ore.	Geijsbeek Engineering Company
GELSTHARP, FREDERICK, Creighton, Pa.	Chemist, Pittsburg Plate Glass Company
GRADY, ROBERT F., St. Louis, Mo.	Manager, The St. Louis Terra Cotta Company
GREAVES-WALKER, ARTHUR F., Tudor Hall, University Parkway, Baltimore, Md.	Representative, American Refractories Company
HARROP, CARL B., E.M., Columbus, Ohio	Assistant Professor Ceramic Engineering, Ohio State University
HART, EDWARD, PH.D., Easton, Pa.	Professor of Chemistry, Lafayette College
HENDERSON, HERBERT B., B.Sc., 1538 N. High St., Columbus, Ohio	Superintendent, Orton Pyrometric Cone Factory
HICE, RICHARD R., E.M., Beaver, Pa.	State Geologist, Topographic and Geological Survey Commission of Pennsylvania

* Died October 26th, 1916.
* Died April 8th, 1917.

HILL, ERCILL C., 401 Vernon Ave., Long Island City, N. Y.	Chemist, New York Architectural Terra Cotta Company
HOPE, HERFORD, Beaver Falls, Pa.	Mayer China Company
HOTTINGER, ADOLPH F., Chicago, Ill.	Northwestern Terra Cotta Company
HOWAT, WALTER L., CR.E., Perth Amboy, N. J.	Research Chemist, Atlantic Terra Cotta Company
HULL, WALTER A., E.M., (in Cer.) 40th and Butler Sts., Pittsburgh, Pa.	United States Bureau of Standards
HUMPHREY, DWIGHT ELMER, Akron, Ohio	Secretary, Portage Engineering Company
HUMPHREY, HAROLD P., E.M., (in Cer.) Trenton, N. J.	Cook Pottery Company
HURSCH, RALPH KENT, B.S., Urbana, Ill.	Assistant Professor in Ceramic Engineering, University of Illinois
JACKSON, C. EDWARD, Wheeling, W. Va.	President, Warwick China Company
KARZEN, SAMUEL CHARLES, CR.E., Uhrichsville, Ohio	Plant Superintendent, American Sewer Pipe Company
KERR, CHARLES HENRY, CR.E., Southbridge, Mass.	Director, Research Laboratory, American Optical Company
KIRK, CHARLES J., New Castle, Pa.	President and General Manager, Universal Sanitary Manufacturing Company
KLEIN, ABRAHAM ALBERT, Worcester, Mass.	Petrographer Research Laboratory, Norton Company
KREHBIEL, JUNIUS F., 1612 Thorn St., Chicago Heights, Ill.	Advance Terra Cotta Company
LANDRUM, ROBERT D., B.S., M.S., Cleveland, Ohio	Manager, Service Department, Harshaw, Fuller and Goodwin Company
LOVEJOY, ELLIS, E.M., Schultz Bldg., Columbus, Ohio	Manager, Lovejoy Engineering Company
MAYER, ARTHUR ELLIS, Beaver Falls, Pa.	Assistant Secretary, Mayer China Company, Limited
MAYER, ERNEST, Beaver Falls, Pa.	Mayer China Company, Limited
MINTON, ROY H., E.M., (in Cer.) Metuchen, N. J.	Superintendent, General Ceramics Company
MONTGOMERY, E. T., E.M., (in Cer.) Detroit, Mich.	Ceramic Engineer, Jeffery-Dewitt Company
MONTGOMERY, ROBERT J., CR.E., Mellon Institute, Pittsburgh, Pa.	Research Department, H Koppers Company
MOORE, JOSEPH K., B.SC., 606 Wooster Ave., Canal Dover, Ohio	Ceramic Engineer, Robinson Clay Products Company, Akron, Ohio
OGDEN, ELLSWORTH, E.M., (in Cer.) Columbus, Ohio	Assistant of Research in Ceramic Engineering, Ohio State University

ORTON, EDWARD, JR., E.M., Fort Sam Houston, San Antonio, Texas	Major in Headquarters Southern Department, Office of Department Quartermaster
PARKER, LEMON, 1314 Morganford Road, St. Louis, Mo.	Vice President and Superintendent, The Parker-Russell Mining and Manufacturing Company
PARMELEE, CULLEN W., B.SC., Urbana, Ill.	Professor in Ceramic Engineering, University of Illinois
PENCE, FORREST K., B.A., CR.E., Zanesville, Ohio	Ceramic Engineer, American Encaustic Tile Company
POSTE, EMERSON P., B.S., Elyria, Ohio	Chemical Engineer, The Elyria Enameled Products Company
POTTS, AMOS PEASLEE, CR.E., Mason City, Iowa	Mason City Brick & Tile Company
PURDY, ROSS C., CR.E., Worcester, Mass.	Director of Research Engineering, Norton Company
RADCLIFFE, BARNEY S., A.B., M.SC., (in Cer.) 1515 Lumber Exchange Bldg., Chicago, Ill.	Midland Terra Cotta Company
RICHARDSON, WILLARD D., A.M., Hebron, N. Dak.	General Manager, Hebron Fire and Pressed Brick Company
RIDDLE, FRANK H., 40th and Butler Sts., Pittsburgh, Pa.	United States Bureau of Standards
RIES, HEINRICH, PH.D., Ithaca, New York	Professor Economic Geology, Cornell University
SHAW, JOSEPH BRADFIELD, CR.E., Alfred, N. Y.	Assistant Director, New York State School of Clay-Working and and Ceramics
SILVERMAN, ALEXANDER, PH.B., A.B., M.S., Pittsburgh, Pa.	Head Department of Chemistry University of Pittsburgh
SIMCOE, GEORGE, North East, Md.	Superintendent and General Manager, Octagon Insulator and Ceramic Company
STALEY, HOMER F., A.B., Ames, Iowa	Professor Ceramic Engineering, Iowa State College
STEPHANI, WILLIAM J., Crum Lynne, Pa.	Superintendent, The O. W. Ketcham Terra Cotta Co
STOUT, WILBER, Columbus, Ohio	Geological Survey of Ohio
STOVER, EDWARD C., 474 W. State St., Trenton, N. J.	Assistant General Manager, Trenton Potteries Company
STULL, RAY THOMAS, E.M., (in Cer.), Lord Hall—O. S. U.—Columbus, O.	Chief Eingineer, Ceramic Research Station, U. S. Bureau of Mines
TEETOR, PAUL, Cambridge, Ohio	Guernsey Earthenware Company
WALKER, FRANCIS W., PH.G., Beaver Falls, Pa.	Secretary and Treasurer, Beaver Falls Art Tile Company

WALKER, FRANCIS W., JR., B.S., (in Cer.) Beaver Falls, Pa.	Superintendent, Beaver Falls Art Tile Company
WARD, J. W., 628 E. Main St., Latrobe, Pa.	General Superintendent, Pittsburgh High Voltage Company
WATTS, ARTHUR S., Columbus, Ohio	Professor Ceramic Engineering, Ohio State University
*WEELANS, CHARLES, Trenton, N. J.	
WHEELER, HERBERT A., E.M., 408 Locust St., St. Louis, Mo.	Consulting Engineer, Mining, Metallurgical and Ceramic Work
WILLIAMS, ARTHUR E., 40th and Butler Sts., Pittsburgh, Pa.	United States Bureau of Standards
WILLIAMS, IRA A., M.Sc., Corvallis, Oregon	Professor Ceramics, Oregon School of Mines, Ceramist, State Bureau of Mines and Geology

FOREIGN ASSOCIATE MEMBERS

AYER, KENNETH B., B.A., B.Sc., Fort William, Ontario, Canada.	Manager, Superior Brick Company, Limited
BARRETT, MAURICE, 93 Clarendon Road, Leeds, England	Chemical Engineer
CARTER, OWEN, "Wykeham," Poole, England	Carter Encaustic Tile Works
CLUXTON, W. HAROLD, Peterborough, Ontario, Canada.	Superintendent, Porcelain Department, Canadian General Electric Company
COBB, JOHN W., Leeds, Yorkshire, England	Professor Fuel Department, The University
COULTER, ALLEN S., CR.E., Reisholz bei Dusseldorf, Germany	Deutsche-Carborundum-Werke
CRONQUIST, GUSTAV WERNEISSON, C.E Torekow, Sweden	Secretary, Consulting Engineer and Editor, The Association of Swedish Brick Industry
DAVIS, N. B., B.Sc., M.A., 28 Frontenac St., N., Kingston, Ont., Canada	Economic Geologist
DEB, SATYA SUNDAR, 45 Taugra Road, Calcutta, India	Manager, Calcutta Pottery Works
DE LUZE, HENRI, Avenue de Poitiers, Limoge, France	Ingenieur des Arts and Manufacture, Theodore Haviland Porcelain Manufactory
DORST, MAX, M.E., Oberlin, S. M., Germany.	Representative, Maschiner Fabrik Dorst
ELEOD, KENDE, Muzeumutca No. 12, Kassa, Hungary.	

* Died Dec. 12th, 1916.

EMERY, GEORGE, Fourth Ave., W., Hamilton, Ontario, Canada	Assistant Superintendent Canadian Porcelain Company
FREDRIKSSON, NILS, Svedala, Sweden	Director of Ceramic School
FUJIOKA, KOJI, CR.E., Kyoto, Japan	Ceramic Engineer, Shofu Procelain Manufacturing Company
GABY, F. A., B.A.SC., 709 Continental Life Bldg., Toronto, Ontario, Canada	Chief Engineer, Hydro-Electric Power Commission
GODDARD, WALTER T., E.E., Hamilton, Canada	Canadian Porcelain Company
GRIFFIN, CARL H., Wesseling Bei Koeln, Germany	Care Deutsche Norton Geselschaft, M. V. H
HARKORT, HERMANN, DR. ING., Driesen, Ostbahn, Germany.	Technical Director, Steingutfabrik, Vordamm
HAVILAND, JEAN, Limoge, France	Technical Director, Haviland and Company
HEINZ, GUSTAV, Neuhaus, am. Rwg., Thuringia, Germany.	
HIRANO, KOSUKE, Tokyo, Japan	Professor Ceramic Department in Higher Technological School of Japan
HOURSOURIPE, JUAN, CR.E., Lincoln, F. C. O., Prov. de Buenos Ayres, Argentine Republic	"Estancia San Antonio"
KING, CHARLES ARTHUR, M.SC., Near Leeds, Yorkshire, England	Technical Chemist, Farnay Iron Company
KITAMURA, YAICHIRO, Tokyo, Japan	Chief of the Ceramic Division of the Government Industrial Laboratory
KNAPP, ERNEST W., B.S., (in Cer.), 162 Fulton Ave., Toronto, Canada	Superintendent Sun Brick Company, Limited
KONDO, SEIJI KOGAKUSHI, Tokio, Japan	Professor, Tokio Higher Tecnnical School
LUNDGREN, HUGO JOHANSON, Peterborough, Ontario, Canada	Superintendent, The Canadian General Electric Company
LUSBY, CHARLES A., Amherst, Nova Scotia	Secretary-Treasurer, Amherst Foundry Company, Limited
MARSON, PERCIVAL, Edinburgh, Scotland	Edinburgh and Leith Glass Works, W. Norton Park
MELLOR, J. W., PH.D., 19 Villas, Stoke-on-Trent, England	Instructor in Pottery and Porcelain, Victoria Institute
MILLAR, JOHN B., Clayburn, British Columbia	Clayburn Company, Limited
MISUMI, AIZO, Tobata, near Moji, Japan	Superintendent, Mikujama Factory, Asahi Glass Company
MOMOKI, SABURO, 84 Kobyashi-Cho, Nagoya, Japan	Ceramic Engineer, Nippon Toki Gomei Kwaisha
OKURA, KAZUCHIKA, M.A., 84 Kobyashi-Cho, Nagoya, Japan	Directing Manager of Japan Porcelain Corporation

PIKE, LEONARD G., M.A., Wareham, Dorsetshire, England	Managing Partner, Pike's Clay Mines
RAMSDEN, CYRIL E., Watlands Ave., Wolstanton, Stoke-on-Trent, England.	Technical Chemist
SAILLY, PAUL, 54 Rue la Botie, Paris, France	Manager, Campagnie General d'Electricite
SEGSWORTH, W. E., B.S., M.E., 103 Bay St., Toronto, Canada	Consulting Engineer, Pennsylvania Feldspar Company
SHANKS, DOUGLAS, Barrhead, near Glasgow, Scotland	Manager, Shanks and Company, Limited, Victorian Pottery
SHANKS, JOHN ARTHUR GORDON, Barrhead, near Glasgow, Scotland	Shanks and Company, Limited, Sanitary Engineers
SOMMERSCHUH, EMIL, Rakonitz, Bohemia, Austria.	General Director, Liechtenstein Stoneware Factory
SWEET, GEORGE A., F.G.S., "The Close," Brunswick, Victoria, Australia	Proprietor of the Brunswick Brick, Tile and Pottery Works
THOMAS, CHARLES WILLIAM, Clifton House, Old Swinford Stourbridge, England	Major
TURNER, WILLIAM ERNEST STEPHEN, B.Sc. ,M.Sc., The University, Sheffield, England	Director of Department, Glass Technology
UMEDA, OTOGORO, Shinagawa, Tokyo, Japan	Engineer, Shinagawa Hakurengwa Kwaisha
VILLALTA, JOHN F. R., Barcelona, Spain	Agent American Clay Machinery Company
WALKER, EDGAR E., Mitcham, Victoria, Australia	Managing Director Australian Tesselated Tile Company

RESIDENT ASSOCIATE MEMBERS

ACHESON, EDWARD GOODRICH, Niagara Falls, N. Y.	President, Acheson Company
ALLEN, FRANCIS BOUTELLE, CR.E., Woodbridge, N. J.	Federal Terra Cotta Company
ANDERSON, ROBERT ELMER, CR.E., 402 W. Boylston St., Worcester, Mass.	Norton Company
APPLEGATE, D. H., JR., Red Bank, N. J.	Manager, Crescent Brick Company
ARBOGUST, CHARLES O., CR.E., 445 Plymouth Court, Chicago, Ill.	Manager Service Department, Brick and Clay Record
ARNOLD, HOWARD CLINTON, B.S., (in Cer.) Urbana, Ill.	Instructor in Ceramic Engineering, University of Illinois
ASHBAUGH, CHARLES C., East Liverpool, Ohio	Secretary--Treasurer, West End Pottery Company

AUSTIN, ARTHUR O., A.B., 326 N. Sixth St., Barberton, Ohio	Chief Engineer, Ohio Insulator Co
AYARS, ERLING ELI, B.SC., (in Cer.), Alfred, N. Y.	Alfred University
BABCOCK, GROVER, M.S., (in Cer.), Wellsville, N. Y.	
BACHER, H. ROBERT, Rock Tavern, N. Y.	
BACON, RAYMOND FOSS, B.S., M.A., PH.D., Pittsburgh, Pa.	Associate Director, Mellon Institute, University of Pittsburgh
BAGGS, ARTHUR E., Marblehead, Mass.	Manager, Marblehead Pottery
BAILAR, JOHN C., B.S., M.A., Golden, Colo.	Assistant Professor of Chemistry, Colorado School of Mines
BAINBRIDGE, W. L., B.S., Newark, Ohio	Chemical Engineer, American Bottle Company
BAKER, G. V., Barnard, N. Y.	Superintendent, Pennsylvania Feldspar Company
BALMERT, RICHARD M., 93 E. Lexington St., Baltimore, Md.	Chesapeake Terra Cotta Company
BALZ, GEORGE ADAM, M.E., Keasbey, N. J.	General Manager, Didier-March Company
BARKER, CHARLES E., Matawan, N. J.	Ceramic Tile Manaufacturer
BARTELLS, H. H., Bessemer, Lawrence Co., Pa.	Bessemer Limestone Company
BARTLETT, EDWARD E., B.SC., Sapulpa, Oklahoma	Bartlett-Collins Glass Company
BASSETT, LEON BURDETTE, 9 John St., Worcester, Mass.	Ceramic Engineer, Norton Company
BATES, CHARLES EMMETT, 542 E. Grove St., Galesburg, Ill.	Student Ceramic Engineering, University of Illinois
BEDSON, WILLIAM, R. D. 4, Lawrence Road, Trenton, N. J.	Assistant Manager, Elite Pottery Company
BELL, FRED SMITH, 1318 Wright Bldg., St. Louis, Mo.	Vice President, The Mandle Clay Mining Company
BELL, M. LLEWELLYN, B.S., 407 Franklin Ave., Wilkinsburg, Pa.	Carnegie Steel Company, Braddock, Pa.
BENTLEY, LOUIS LEES, M.E., Beaver Falls, Pa.	Superintendent, Armstrong Cork Company
BERRY, CHARLES W., St. Louis, Mo.	Chemist, Laclede-Christy Clay Products Company
BEST, HAROLD A., Box 35, Haydenville, Ohio	National Fireproofing Company
BISH, HOWARD A., Carey, Ohio	Assistant Superintendent, National Electric Porcelain Company
BISSELL, GEORGE FRANCIS, Ottawa, Ill.	Chicago Retort and Fire Brick Company

BLACKMER, EDWARD LESLIE, 501 Clara Ave., St. Louis, Mo.	Assistant Superintendent Blackmer and Post Pipe Company
BLAIR, MARION W., M.E., Thornton, W. Va.	Superintendent Thornton Fire Brick Company
BLAIR, WILLIAM P., Cleveland, Ohio	Secretary, National Paving Brick Manufacturers' Association
BLAKE, ALFRED E., Pittsburgh, Pa.	Mellon Institute, University of Pittsburgh
BLEWETT, J. B., CR.E., Wellsville, Ohio	The McLain Fire Brick Company
BLOOMFIELD, CHARLES A., Box 652, Metuchen, N. J.	Treasurer, Bloomfield Clay Company
BOECK, PERCY A., 227th St. and Spuyten Duyvil Parkway, New York, N. Y.	Chemical Engineer
BOORAEM, J. FRANCIS, M.E., E.E., 1182 Broadway, New York, N. Y.	Treasurer and Manager, American Enameled Brick and Tile Company
BOOZE, MACDONALD CHARLES, Carrollton, Ohio	Medal Paving Brick Company
BOWER, HENRY L., Trenton, N. J.	J. L Mott Company
BOWMAN, 2ND, OLIVER OTIS, Trenton, N. J.	Ceramist, Trenton Fire Clay and Porcelain Company
BOWMAN, WILLIAM J. J., C.E., Trenton, N. J.	Trenton Fire Clay and Porcelain Company
BRAGDON, WILLIAM V., B.SC., (in Cer.), 2336 San Pablo Ave., Berkeley, Calif.	The "Tile Shop"
BRAND, JOHN JULIUS FREDERICK, 1317 Camp St., Sandusky, Ohio	
BRANDT, GEORGE F., Box 314, Minerva, Ohio	Clay Shop Foreman, Owen China Company
BRAY, ARCHIE C., CR.E., Helena, Mont.	Assistant Superintendent, General Ceramic Work, Western Clay Manufacturing Company
BREWSTER, ROBERT, 2814 Cambridge Ave., Chicago, Ill.	Dental Porcelain Manufacturing Company
BRIGGS, LEONARD S., South River, N. J.	National Fireproofing Company
BROCKMAN, EDWARD A., 192 W. Clark St., Chicago, Ill.	Salesman, Roessler and Hasslacher Chemical Company
BROWER, FRED W., CR.E., Barrington, R. I.	Yard Superintendent, Barrington Steam Brick Company
BROWN, EDMUND, Perrysburg, Ohio	General Manager Edward Ford Plate Glass Company
BROWN, L. K., Zanesville, Ohio	Vice President, The Burton Townsend Company
BROWN, LESLIE, Trenton, N. J.	Ceramist, Lenox Incorporated

Brown, Philip King, A.B., M.D., Physicians' Bldg., 516 Sutter St., San Francisco, Cal.	
Brown, R. E., Utica, Ill.	Utica Fire Brick and Clay Co
Brown, Richard P., Wayne Junction, Philadelphia, Pa.	President, Brown Instrument Company
Brown, Wilbur F., A.B., Muncie, Ind.	Chemist, Ball Brothers Glass Manufacturing Company
Browning, T. S., 405 E. John St., Champaign, Ill.	Student, Ceramic Engineering, University of Illinois
Bruner, Willard Lynn, 196 Water St., Perth Amboy, N. J.	Ceramic Chemist, Roessler and Hasslacher Chemical Company
Bryan, Merrill L., Seattle, Wash.	Superintendent, Terra Cotta Department, Denny-Renton Clay and Coal Company
Bucher, Ermane Gaylord, B.S., (in Cer.), Y. M. C. A., Streator, Ill.	Des Moines Clay Company, Des Moines, Iowa
Buckner, O. S., Y. M. C. A., 32 Pearl St., Worcester, Mass.	The Norton Company
Burr, Robert Brinkerhoff, Columbus, Ohio	Logan Natural Gas and Fuel Company
Butterworth, Frank W., Danville, Ill.	General Manager, Western Brick Company
Byers, Louis L., 501 E. Daniel St., Champaign, Ill.	Student in Ceramic Engineering, University of Illinois
Cable, Davis A., M.E., East Sparta, Ohio	General Superintendent, United States Roofing Tile Company
Cable, Margaret Kelly, Grand Forks, N. D.	Instructor in Ceramics, College of Mining Engineering, University of North Dakota
Campbell, A. R., Metuchen, N. J.	Federal Terra Cotta Company
Carder, Frederic R., Corning, N. Y.	Manager and Chemist, Stuben Glass Works
Carmen, Charles Ford, C.E., Berkeley Springs, W. Va.	President, National Silica Works
Carrier, Augustus, B.S., (in E.E.), 20 Milwaukee Ave., W., Detroit, Mich.	Chemist, Detroit Dental Manufacturing Company
Case, W. W., Jr., Denver, Colo.	President and Manager, Denver Fire Clay Company
Casey, Charles L., D.D.S., Cambridge, Ohio	President Guernesy Earthenware Company
Cermak, Frank, 116th 4th Ave., Schenectady, N. Y.	Foreman, Porcelain Works, General Electric Company
Chambers, A. Reeder, 466 Greenwood Ave.	Fire Brick Manufacturer
Chase, John Albion, Box 163, Oak Park, Ill.	

CHASE, MARCH F., B.Sc., Depue, Ill.	General Superintendent, Mineral Point Zinc Company; Greendale Plant
CHENEY, M. B., CR.E., Briggsdale, Ohio	
CHILD, J. L., Findlay, Ohio	Hancock Brick and Tile Company
CHORMANN, OTTO IRVING, 122 First St., Niagara Falls, N. Y.	Major, 3rd New York Infantry N. G.
CLARE, ROBERT L., CR.E., Woodbridge, N. J.	Superintendent, Federal Terra Cotta Company
CLARK, ARTHUR B., M.AR., Stanford University, California	Head Department of Graphic Arts, Leland Stanford Junior University
CLARK, HAROLD EDWARD, Malvern, Ohio	Robinson Clay Products Company
CLARK, JOHN, 292 Lockwood St., Astoria, N. Y.	Superintendent New York Architectural Terra Cotta Company
CLARK, WILLIAM M., PH.B., E. 152nd St., Cleveland, Ohio	Manager, Euclid Glass Division, National Lamp Works of General Electric Company
COLE, M. J., Logan, Ohio	Superintendent and Treasurer, The Logan Clay Products Company
CONKLING, SAMUEL O., Philadelphia, Pa.	Superintendent, Conkling-Armstrong Terra Cotta Company
COOKE, M. E., 1550 Clifton Ave., Columbus, Ohio	Studio for Architectural Sculpture
COVAN, H. E., Cleveland, Ohio	Price Electric Pyrometer Company
COX, HAROLD NEWTON, B.Sc., Woodhaven, N. Y.	Chief Chemist and Division Superintendent, Lalance and Grosjean Manufacturing Company
COX, PAUL E., B.S., (in Cer.), 2828 Camp St., New Orleans, La.	Ceramic Technician, Newcomb Pottery
COX, S. FRANK, A.B., S.M., Creighton, Pa.	Research Chemist, Pittsburgh Plate Glass Company
CRAWFORD, EDWARD ANDERSON, B.L., Canastota, R. D., New York	
CRAWFORD, J. LEWIS, 601 S. Fourth St., Champaign, Ill.	Student, Ceramic Engineering University of Illinois
CREIGHTON, ELMER E. F., B.S., E.E., 27 Wendell Ave., Schenectady, N. Y.	Consulting Electrical Engineer, General Electric Company
CREW, HORACE FLEMING, CR.E., East Chicago, Ind.	Ceramic Engineer, Green Engineering Company
CRONIN, WILLIAM KRESS, 320 W. Fifth St., East Liverpool, Ohio	Standard Pottery Company
CUTTING, J. WORCESTER, Cambridge, Mass.	Superintendent, A. H. Hews and Company, Incorporated
DANIELSON, RALPH RAYMOND, M.S., Des Plaines, Ill.	Chemist, Rays Enameling Company

DARLING, JAMES,
P. O. Box 300, Kenova, W. Va.

DAVIS, JOHN BOYNTON, A.B., D.M.D., Dentist
22 E. Greenwood Ave., Lansdowne, Pa.

DEAN, CHARLES A., CR.E., Ceramic Engineer, Research Laboratories, Norton Company
Worcester, Mass.

DEAVER, ALWARD LISTER, B.S., (in Chem.), Robinson Clay Products Company
Akron, Ohio

DICKEY, FRED L., General Manager, W. S. Dickey Clay Manufacturing Company
200 New York Life Bldg., Kansas City, Mo.

DOBBINS, T. MONROE, Secretary and Treasurer, Camden Pottery Company
Camden, N. J.

DORNBACH, WM. E., Superintendent Auburn Shale Brick Company
Auburn, Pa.

DRAKENFELD, B. F., JR., Treasurer, B. F. Drakenfeld and Company, Incorporated
50 Murray St., New York, N. Y.

DUNN, FRANK B., President and Treasurer, Dunn Wire Cut Lug Brick
Conneaut, Ohio

DUVAL, ALEXANDER L., Chief Chemist, Hazel-Atlas Glass Company
Washington, Pa.

DYER, BRAINERD, A.B., B.S., Head of Publicity Division, National Carbon Company
Cleveland, Ohio

EARLE, ROBERT WALLACE, Vice President, Dover Manufacturing Company
Canal Dover, Ohio

EBINGER, DAVID HUGO, M.E., Superintendent, D. A. Ebinger Sanitary Manufacturing Company
Columbus, Ohio

EDGAR, DAVID RAYMOND, Assistant General Manager, Edgar Brothers' Company
Metuchen, N. J.

ELLERBECK, WM. LEON, D.D.S., Manager Nephi Plaster and Manufacturing Company
703 Boston Bldg., Salt Lake City, Utah

ESKESEN, BENNET K., Superintendent, N. J. Mosaic Tile Company
Matawan, N. J.

ESKESEN, ECKARDT V., General Manager, New Jersey Terra Cotta Company
149 Broadway, New York, N. Y.

EVATT, FRANK G., District Manager, Atlantic Terra Cotta Company
705 Fulton Bldg., Pittsburgh, Pa.

FACKT, GEORGE P., General Manager, Denver Terra Cotta Company
Denver, Colo.

FALKENBURG, M. J., M.S., Falkenburg and Laucks, Consulting, Analytical, Inspecting Chemists and Engineers
95 Yesler Way, Seattle, Wash.

FARREN, MABEL C., Instructor in Ceramics, Carnegie Institute of Technology
303 B Iroquois Aparts., 3600 Forbes St., Pittsburgh, Pa.

FERGUSON, RICHARD D., Treasurer, Yankee Hill Brick Company
1700 E St., Lincoln, Nebr.

FISHER, DOUGLAS J., Sayre and Fisher Company
Sayreville, N. J.

FISHER, GEORGE P., CR.E., Ottawa, Ill.	National Fireproof Company
FOERSTERLING, HANS, PH.D., 380 High St., Perth Amboy, N. J.	Second Vice-President, Roessler-Hasslacher Chemical Company
FORD, G. BERGEN, B.SC., Philadelphia, Pa.	Ceramic Chemist, Conkling-Armstrong Company
FORESTER, HERBERT, Box 37, Cleveland, Ohio	Principal, Veritas Firing System Company
FORST, ARTHUR D., B.S., Trenton, N. J.	President, Robertson Art Tile Company
FORST, DANIEL PARRY, A.B., 73 N. Clinton Ave., Trenton, N. J.	Robertson Art Tile Company
FRASER, W. B., Wilson Bldg., Dallas, Texas	President, Fraser Brick Company
FROST, LEON JAMES, 178 Northfield Ave., East Cleveland, Ohio	Chemist and Purchasing Agent, Enamel Products Company
FRERICHS, WILLIAM D., 111 Broadway, New York, N. Y.	Federal Terra Cotta Company
FUHRMANN, FRANK J., 1807 College Ave., Des Moines, Iowa	
FULLER, RALPH L., Cleveland, Ohio	Partner, Harshaw, Fuller & Goodwin Company
FULPER, WM. H., Flemington, N. J.	Secretary and Treasurer, Fulper Pottery Company
FULTON, KENNETH I., B.S., CR.E., 316 E. Main St., Portland, Ind.	Citizens Gas and Oil Mining Company
GALLOWAY, WALTER B., B.S. (in Arch.), Walnut and 32nd St., Philadelphia, Pa.	President, Galloway Terra Cotta Company
GARRISON, AMOS, Pocatello, Idaho	Farmers and Traders Bank
GATES, A. W., Colchester, Ill.	President and Treasurer, Gates Fire Clay Company
GATES, MAJOR E., Terra Cotta, Ill.	Superintendent American Terra Cotta and Ceramic Company
GAVIN, GORDON P., 524 Riverside Drive, Trenton, N. J.	Monument Pottery Company
GEIGER, CHARLES F., 219 Lawrence Ave., Highland Park, New Brunswick, N. J.	Rutgers College
GERBER, ALBERT C., 45 Coit Ave., Cleveland, Ohio	Steel Enameling Department, Cleveland Metal Products Company
GIBBS, ARTHUR EDWARD, 1006 Widener Bldg., Philadelphia, Pa.	Head of Research Department, Pennsylvania Salt Manufacturing Company
GILDARD, WARREN R., Creighton, Pa.	Research Chemist, Pittsburgh Plate Glass Company
GLADDING, AUGUSTUS L., B.SC., Lincoln, Calif.	Gladding, McBean and Company

GODFREY, LYDIA B., PH.B., Grand-View-on-Hudson, N. Y.	Director, Glen Tor Keramic Studio
GOLDING, CHARLES E., Rear 217 S. Warren St., Trenton, N. J.	Manager, Trenton Department of Golding Sons Company
GOOD, HARRY N., CR.E., 328 Market St., Clearfield, Pa.	Ceramic Engineer, Pittsburg Testing Laboratory
GRAINER, JOHN S., 70 Cleveland St., Battle Creek, Mich.	Foreman, A. B. Stove Company
GRANT, DEFOREST, B.A., 111 Broadway, New York, N. Y.	President Federal Terra Cotta Company
GRANT, W. HENRY, CR.E., 119 Maurus St., St. Marys, Pa.	Elk Fire Brick Company
GREEN, J. L., C.E., St. Louis, Mo.	President, LaClede-Christy Clay Products Company
GREENE, R. W., Mayfield, Ky.	General Manager, Kentucky Construction and Improvement Company
GREENER, GEORGE C., E.M., (in Cer.), Boston, Mass.	Director North Bennett Street Industrial School
GREGORI, JOHN N., Chicago, Ill.	Kiln Burner, Northwestern Terra Cotta Company
GREGORY, M. E., Corning, N. Y.	Proprietor, Corning Brick, Terra Cotta and Tile Company
GREGORY, MORRIS C., CR.E., Corning, N. Y.	Ceramic Engineer, Corning Brick, Terra Cotta and Tile Company
GRUEBY, WILLIAM H., Boston, Mass.	President, General Manager, Grueby Faience Company
GUASTAVINO, RAFAEL, JR., The Fuller Bldg., 949 Broadway, New York, N. Y.	President, The R. Guastavino Company
GUNNISS, WILLIAM HEROLD, Black Eagle Club, Great Falls, Mont.	
HAAF, GEORGE, 1501 Milton Ave., Solvay, N. Y.	General Foreman, Pass and Seymour Incorporated
HAEGER, E. H., Dundee, Ill.	Haeger Brick and Tile Company
HALL, HERMAN A., CR.E., Logan, Ohio	Superintendent, Hocking Valley Brick Company
HALL, ROBERT T., East Liverpool, Ohio	Secretary and Treasurer, Hall China Company
HAMILTON, JAMES, Trenton, N. J.	Superintendent, Ideal Pottery of Trenton Potteries Company
HANDKE, PAUL ALBERT, 260 S. Academy St., Galesburg, Ill.	Purington Paving Brick Company
HANSEN, ABEL, Fords, N. J.	Proprietor and Manager, Fords Terra Cotta and S. Works
HARDY, ISAAC ERNEST, Momence, Ill.	Superintendent, Tiffany Enameled Brick Company
HARE, ROBERT L., Fulton, Mo.	Superintendent, Fulton Fire Brick Company

HARKER, H. N., East Liverpool, Ohio	General Manager, Harker Pottery Company
HARPER, JOHN LYALL, Niagara Falls, N. Y.	Chief Engineer, Niagara Falls Hydraulic Power Company
HARRIS, CHARLES T., 824 Engineers Bldg., Cleveland, Ohio	Secretary, Hollow Building Tile Manufacturers' Association of America
HASBURG, JOHN W., 1119 La Salle Ave., Chicago, Ill.	President, John W Hasburg Company, Incorporated
HASSLACHER, JACOB, 100 William St., New York, N. Y.	President, The Roessler and Hasslacher Chemical Company
HASTINGS, FRANCIS N., Hartford, Conn.	Hartford Faience Company
HEILMAN, KARL JOHN, B.S., Tiffin, Ohio	Proprietor, Tiffin Brick Company
HENRY, ARTHUR VAN, CR.E., 737 Oak St., Columbus, Ohio	Ceramic Engineer, Pittsburgh Testing Laboratory
HENRY, FRANK R., Dayton, Ohio	Manager, Dayton Grinding Wheel Company
HEPLER, I. F., Narberth, Pa.	Chief Engineer, General Refractories Company
HIPP, RALPH T., Massillon, Ohio	
HIPP, WILLIAM G., Massillon, Ohio	Secretary and General Manager, Massillon Stone and Fire Brick Company
HITCHINS, E. S., Olive Hill, Ky.	General Manager, General Refractories Company
HOEHN, JOHN FREMONT, B.S., 119 Bridge St., Peoria, Ill.	Peoria Brick and Tile Company
HOFFMAN, GEORGE E., Trenton, N. J.	Secretary, Monument Pottery Company
HOLMES, HAROLD W., B.S., in M.E., 710 Farwell Bldg., Detroit, Mich.	Puritan Brick Company
HOOD, B. MIFFLIN, Atlanta, Georgia	President, Mifflin Hood Brick Company
HORNING, ROY A., B.S., Beaver Falls, Pa.	Chemist, Armstrong Cork Company
HORNUNG, MARTIN ROBERT, B.S., (in Cer.), Y. M. C. A., Wheeling, W. Va.	Wheeling Tile Company
HOSTETLER, GARRISON R., Sugar Creek, Ohio	Superintendent, The Sugar Creek Clay Products Company
HOWE, RAYMOND MILLER, B.S., 155 N. Craig St., Pittsburgh, Pa.	Fellow in Glass, Department of Chemistry, University of Pittsburgh
HUMMELAND, RALPH W., 916 W. Green St., Urbana, Ill.	Student in Ceramic Engineering, University of Illinois
HUNT, F. SUMNER, B.S., Beaver Falls, Pa.	Beaver Falls Art Tile Company

IRELAND, HARLEY R., Brazil, Ind.	Assistant Secretary and Treasurer, Hydraulic Press Brick Company
IRWIN, DEWITT D., East Liverpool, Ohio	Secretary, Potters Supply Company
JACOBS, WILLIAM MCFALLIN, CR.E., Charleroi, Pa.	Pittsburgh Plate Glass Company
JACQUART, CHARLES EDWARD, B.S., South River, N. J.	Ceramist, American Enameled Brick Company
JEFFERY, JOSEPH ARTHUR, D.D.S., Detroit, Mich.	President and General Manager, Jeffery-Dewitt Company
JENKINS, NEWELL SILL, D.D.S., 180 Meadow St., New Haven, Conn.	
JENSEN, CHARLES HENRY, 156 Greene St., Brooklyn, N. Y.	President, Empire China Works
JEPPSON, GEORGE N., Worcester, Mass.	Works Manager, Norton Company
JOHNSON, ARTHUR AUGUST VICTOR, 247 Sheridan St., Zanesville, Ohio	Draughtsman and Designer, L. E. Rogers Engineering Company
JOHNSTON, ROBERT MARCH, M.E., 692 Cadillac Ave., Detroit, Mich.	
JONES, OTIS L., Oglesby, Ill.	President and Manager, Illinois Clay Products Company
JONES, ROBERT W., Albany, N. Y.	Economic Geologist, New York State Museum
JUSTICE, ITHAMAR M., Dayton, Ohio	Vice-President, Manufacturers Equipment Company
KALBFLEISCH, G. C., Tiffin, Ohio.	Manager, Standard Sanitary Manufacturing Company
KANENGEISER, FRED R., Bessemer, Pa.	General Superintendent, Bessemer Limestone Company
KEEHN, CLARENCE C., B.A., Canandaigua, N. Y.	Secretary and Assistant Manager Liske Manufacturing Company, Limited
KEELER, RUFUS B., National City, Calif.	
KEESE, HOMER GOLDSMITH, Litchfield, Ill.	Student, Ceramic Engineering, University of Illinois
KENDRICK, LUCIUS S., Williamstown, Mich.	Vice-President and General Manager, Central Michigan Clay Products Company
KEPLINGER, ROBERT BARR, A.B., Canton, Ohio	Assistant General Superintendent, Metropolitan Paving Brick Company
KERR, WALTER B., PH.B., Syracuse, N. Y.	President, Iroquois China Company
KIRKPATRICK, F. A., M.S., 262 Fiske St., Pittsburgh, Pa.	United States Bureau of Standards
KLINEFELTER, THERON ALBERT, A.B., CR.E., Box 510, Derry, Pa.	Ceramic Engineer, Research Dept., Westinghouse Electric and Manufacturing Company

KNIGHT, MAURICE A., B.S., E. Akron, O.	Manufacturer, Acid Proof Chemical Stoneware
KNOLLMAN, HARRY J., 2727 N. Park Ave., Philadelphia, Pa.	Abrasive Company
KOCH, CHARLES FREDERICK, Cincinnati, Ohio	National Sales Company
KOCH, JULIUS J., 3325 Carolina St., St. Louis, Mo.	
KOHLER, WALTER J., Kohler, Wis.	President, J. M. Kohler and Sons Company
KRAUS, CHARLES ERNEST, 350 87th St., Brooklyn, N. Y.	Refractories Engineer, H. W. Johns-Manville Company
KRICK, GEORGE M., Decatur, Ind.	General Manager, Krick, Tyndall and Company
KRIEG, HENRY F., 1515 Lumber Exchange Bldg., Chicago, Ill.	Midland Terra Cotta Company
KRIEG, WILLIAM G., 1515 Lumber Exchange Bldg., Chicago, Ill.	President, Midland Terra Cotta Company
KRUSON, I. ANDREW, B.S.CR., Victor, N. Y.	Locke Insulator Company
LAMBIE, JAMES M., B.S., Washington, Pa.	Vice-President and Assistant General Manager, Findlay Clay Pot Company
LANDERS, WILLIAM FRANKLIN, Indianapolis, Ind.	Superintendent, United States Encaustic Tile Works
LARDIN, R. H., Creighton, Pa.	Assistant Chemist, Research Department, Pittsburgh Plate Glass Company
LARKIN, PAUL GIFFORD, B.SC., CR.E., Denver, Colo.	Ceramic Chemist, Denver Terra Cotta Company
LARKINS, SAMUEL B., Salineville, Ohio	Superintendent National China Company
LAUGHLIN, SAMUEL OTT, Wheeling, W. Va.	President and General Manager, Wheeling Tile Company
LAWSON, CARL HARRY, 3 Fraternal Ave., Worcester, Mass.	Laboratory Assistant, Norton Company
LAYMAN, F. E., E.M. (in Cer.), The Aberdeen, Milwaukee, Wis.	Chemist, Cutler-Hammer Company
LEPAGE, JUST, Willamina, Oregon	Head Burner, Pacific Face Brick Company
LEVINGS, GEORGE VAN B., via Palisade, Nevada	Union Mines
LIBMAN, EARL E., B.S. (in Cer.), 501 Knoxville St., Peoria, Ill.	Assistant Construction Engineer, Illinois Traction System
LINBARGER, SILAS CARL, B.S., Niagara Falls, New York	Carborundum Company
LINDER, CYRIL S., Creighton, Pa.	Pittsburgh Plate Glass Company
LINDLEY, JACOB, Tiltonville, Ohio	Riverside Potteries Company

LLOYD, HARRY, Irondale, Ohio	Superintendent Colonial Clay and Coal Company
LOCKE, FREDERICK M., Victor, N. Y.	Manufacturer of Porcelain Insulators
LONGENECKER, H. L., CR.E., Cambridge, Md.	Manager, Cambridge Brick Company
LOOMIS, GEORGE ALLEN, CR.E., 40th and Butler Sts., Pittsburgh, Pa.	United States Bureau of Standards
LOUTHAN, WM. B., East Liverpool, Ohio	Manager Louthan Supply Company
LUCAS, H. J., 2525 Clybourn Ave., Chicago, Ill.	Vice-President Northwestern Terra Cotta Company
LYON, JOHN BOYD, B.S., 4868 Fountain Ave., St. Louis, Mo.	Laclede-Christy Clay Products Co
MCBEAN, ATHOLL, 311 Crocker Building, San Francisco, Calif.	Secretary, Gladding, McBean and Company
MCCANN, JAMES S., Streator, Ill.	Superintendent, Streator Clay Manufacturing Company
MCCLAVE, J. M., 910 American Trust Bldg., Cleveland, Ohio	General Manager American Fire Clay and Products Company
MCDANEL, WALTER W., 532 Thirteenth Ave., New Brighton, Pa.	Mould Maker, United States Bureau of Standards
MCDOWELL, J. S., B.S., Pittsburgh, Pa.	Research Department, Harbison-Walker Refractories Company
MCDOUGAL, TAINE G., CR.E., Flint, Mich.	Champion Ignition Company
MACGREGOR, JOHN ROY, 1106 Tacoma Bldg., Chicago, Ill.	Chemist, Picher Lead Company
MACKENZIE, WILLIAM G., Wilmington, Del.	Manager, Golding Sons Company, Wilmington, Delaware Department
MACMICHAEL, PAUL S., Auburn, Wash.	President, Northern Clay Company
MCMILLAN, HERBERT G., Detroit, Mich.	Manager and Secretary, Porcelain Enameling and Manufacturing Company
MCNAUGHTON, MALCOLM, M.E., Jersey City, N. J.	Superintendent, Joseph Dixon Crucible Company
MCVAY, T. N., B.S., CR.E., Streator, Ill.	Streator Brick Company
MADDISON, E. A., 3877 25th St., San Francisco, Calif.	Architectural Terra Cotta Draftsman
MADDOCK, A. M., JR., Trenton, N. J.	Vice-President, Thomas Maddocks's Sons Company
MADDOCK, HENRY E., Trenton, N. J.	Wtih John Maddock Sons Company
MADDOCK, JOHN, Trenton, N. J.	John Maddock and Sons
MALINOVSZKY, ANDREW, Lincoln, Ill.	Chemical Engineer

MALM, ARTHUR T., CR.E., Worcester, Mass.	Factory Investigator, Research Laboratories, Norton Company
MALSCH, WERNER, 100 Williams St., New York, N. Y.	Manager, Ceramic Department, The Roessler and Hasslacher Chemical Company
MALTBY, ALFRED, Corning, N. Y.	Superintendent, Corning Brick, Terra Cotta and Tile Company
MANDLE, I., Wright Bldg., St. Louis, Mo.	Secretary and Treasurer, Mandle Clay Mining Company
MANDLE, SYDNEY, Wright Bldg., St. Louis, Mo.	Assistant Treasurer, The Mandle Clay Mining Company
MANDLER, CHAS. J., B.L., LL.B., 2104 Franklin Ave., Toledo, Ohio	President, Allen Filter Company
MANOR, JOHN M., East Liverpool, Ohio	Manager, The Golding Sons Company
MARTZ, JOSEPH ADELBERT, CR.E., Columbus, Ohio	Norton Company
MASON, FORTUNATUS, Q., East Liverpool, Ohio	Mason Color and Chemical Company
MAYER, WALTER STANLEY, B.S., 1520 Third Ave., New Brighton, Pa.	Assistant to Manager, Mayer China Company
MAYNARD, T. POOLE, A.B., PH.D., Atlanta, Ga.	Consulting Geologist
MELLOR, F. G., Wheeling, W. Va.	Warwick China Company
METZNER, OTTO, Cincinnati, Ohio	Superintendent of Manufacture, Rookwood Pottery Company
MIDDLETON, JEFFERSON, 1736 Corcoran St., Washington, D. C.	Statistician, United States Geological Survey
MILLER, DONALD M., 633 Monmouth St., Trenton, N. J.	Secretary, Crossley Machine Company
MILLIGAN, FRANK W., Parkersburg, W. Va.	Manager, General Porcelain Company
MILLSOM, WALTER C., Macomb, Ill.	Student in Ceramics, University of Illinois
MINER, HARLAN S., B.S., (in Ch.), Gloucester City, N. J.	Chief Chemist, Welsbach Company
MOORE, EARL JACKSON, Greenville, Ohio	Superintendent, Richeson, Nelson and Moore
MOORE, HERBERT W., Perth Amboy, N. J.	Chief Chemist, Atlantic Terra Cotta Company
MOORSHEAD, THOMAS COURTNEY, Alton, Ill.	Chief Engineer, Illinois Glass Company
MORGAN, FREDERICK ARTHUR, B.S., 1106 Tacoma Bldg., Chicago, Ill.	Sales Department, Picher Lead Company
MORRIS, GEORGE D., CR.E., St. Louis, Mo.	Superintendent, Evens and Howard Fire Brick Company Works Nos 1 and 2
MOSES, JAMES, Trenton, N. J.	Mercer Pottery Company

MOULTON, D. A., Firebrick, Ky.	Ceramic Engineer
MUCKENHIRN, CHARLES H., 550 Chalmer Ave., Detroit, Mich.	General Representative, Standard Sanitary Manufacturing Company
MUESSIG, C. NICK, Box 267, East Liverpool, Ohio	Salesman, B. F. Drakenfeld, Incorporated
MULHOLLAND, VERGIL, 41 Arch St., Hartford, Conn.	
MUNSHAW, LAMBERT M., North Crystal Lake, Ill.	Ceramist, American Terra Cotta and Ceramic Company
MURRAY, GERARD A., CR.E., Mt. Savage, Md.	Union Mining Company
MYERS, CHARLES H., CR.E., 10 Third Ave., Murray, Utah	Superintendent Murray Plant, Utah Fire Clay Company
MYERS, SCOTT P., Uhrichsville, Ohio	Superintendent, Robinson Clay Product Company
NELSON, IDRIS, A.B., Y. M. C. A., Galesburg, Ill.	Chemist Purington Paving Brick Company
NICELY, CHARLES AUGUSTUS, CR.E., Watsontown, Pa.	
NIES, FREDERICK HAROLD, D.D.S., 859 Bay Ridge Ave., Brooklyn, N. Y.	
OFFICE, LEON R., B.S., in CR.E., Mellon Institute, Pittsburgh, Pa.	Ceramic Chemist, H. Koppers Company, Mellon Institute, Pittsburgh
ORTMAN, FRED B., CR.E., 401 Vernon Ave., Long Island City, N. Y.	Ceramic Engineer, New York Architectural Terra Cotta Company
OUDIN, CHARLES P., 2327 Pacific Ave., Spokane, Wash.	Manager, Pacific Fire Brick Company
OVERBECK, ELIZABETH G., Cambridge City, Ind.	Overbeck Pottery
OWENS, FRANCIS T., Ridgway, Pa.	Treasurer and General Manager, Ridgway Brick Company
PASS, RICHARD HENRY, A.B., Syracuse, N. Y.	Chemist, Onandago Pottery Company
PATTERSON, ALEXANDER, PH.B., M.A., Clearfield, Pa.	Secretary and Treasurer, Patterson Clay Products Company
PELTON, HERBERT EDWARD, A.B., E.E., 1922 Dracena Drive, Los Angeles, Calif.	Secretary and Treasurer, West Coast Tile Company
PENFIELD, L. W., Willoughby, Ohio	Vice-President and Resident Manager, American Clay Machinery Company
PENFIELD, R. C., 1619 Conway Bldg., Chicago, Ill.	President and General Manager, American Clay Machinery Company
PEREGRINE, CLARENCE R., 411 Washington Ave., Charleroi, Pa.	General Superintendent, Macbeth Evans Glass Company
PFAU, CHARLES, Cincinnati, Ohio	President, Pfau Manufacturing Company

PHILLIPS, WILLIAM L., 1261 St. Charles St., Alameda, Cal.	N. Clark and Sons
PIERCE, O. W., Olean, N. Y.	Olean Tile Company
PIERCE, ROBERT H. H., B.A., Box 516 Hazelwood, Pittsburgh, Pa.	Chief Chemist, Harbison-Walker Refractories Company
PITCAIRN, WILLIAM S., 104 Fifth Ave., New York, N. Y.	Importer of China and Earthenware
PLUSCH, HERMAN A., M.Sc., Philadelphia, Pa.	Research Engineer, Abrasive Company
POLEN, GEORGE A., 1012 Wooster Ave., Canal Dover, Ohio	General Superintendent Robinson Clay Products Company
POOLE, JOSHUA, East Liverpool, Ohio	Manager Homer Laughlin China Company
PORTER, FRED BAKER, B.S., CH.E., Fort Worth, Texas	President, Fort Worth Laboratories
POST, MALCOLM P., Commerce, Mo.	Superintendent, Post Brothers
POWELL, WILLIAM H., 200 W. Seventieth St., New York, N. Y.	President, Atlantic Terra Cotta Company
PRESTON, FRANCIS C., 509 Cuyahoga Bldg., Cleveland, Ohio	Vice-President and Sales Manager, Dover Fire Brick Company
PRIMLEY, WALTER S., A.B., 1515 Lumber Exchange Bldg., Chicago, Ill.	Secretary and Treasurer, Midland Terra Cotta Company
PURINTON, BERNARD S., Wellsville, Ohio	United States Pottery Company
PYATT, FRANK E., 128 Sharon Ave., Zanesville, Ohio	
RAINEY, LLOYD B., CR.E., Beaver, Pa.	Superintendent, Fallston Fire Clay Company
RAMSAY, ANDREW, Mt. Savage, Md.	The Andrew Ramsay Company
RAMSAY, JOHN D., St. Marys, Pa.	President and General Manager, Elk Fire Brick Company
RANCKE, LOUIS N., Lonaconing, Md.	Consulting Engineer-Chemist
RANDALL, JAMES E., Indianapolis, Ind.	Junior Editor, Clayworker
*RANDALL, THEODORE A., Indianapolis, Ind.	Editor, Clayworker
RANKIN, GEORGE ATWATER, A.B., (Chemistry), Creighton, Pa.	Chief, Geophysical Department, Pittsburgh Plate Glass Company
RATHFON, WILLIAM O., 7747 Burnham Ave., Chicago, Ill.	Chicago Fire Brick Company
RATHJENS, GEORGE W., B.S., C.E., Fort Snelling, Minn.	Captain Engineer, Officers Reserve Corps

* Life member.

RAYMOND, GEORGE M., 1511 Grand Ave., Dayton, Ohio	General Manager, C. W. Raymond Company
REA, WILLIAM J., Buffalo, N. Y.	Superintendent, Buffalo Pottery Company
REEVE, HOWARD T., F.C.I., South Bridge, Mass.	Chief Scientist, American Optical Company
REYNOLDS, PIERCE B., A.B., 433 Wyoming Ave., Kingston, Pa.	Treasurer, Dorrance Terra Cotta Company
RHEAD, FREDERICK HURTEN, Mission Canyon, Santa Barbara, Calif.	Editor and Manager, Potter Publishing Company
RHOADES, RALPH STANLEY, St. Louis, Mo.	General Manager, Evens and Howard Fire Brick Company
RICHARDSON, ERNEST, Beaver Falls, Pa.	Vice-President and Treasurer, Ingram Richardson Manufacturing Company
RIESS, DEWITT F., Sheboygan, Wis.	Secretary and Factory Manager, Vollrath Company
RIVERS, WILLIAM EDWARD, Old Bridge, N. J.	Vice-President, Old Bridge Enameled Brick and Tile Company
ROBERTSON, FRED. H., 809 N. Alvarado St., Los Angeles, Cal.	Los Angeles Pressed Brick Company
ROBERTSON, HUGH SCHUYLER, B.S., 211 Sycamore St., Pittsburgh, Pa.	Harbison-Walker Refractories Company
ROBINEAU, S. E., 108 Pearl St., Syracuse, N. Y.	President, Keramic Studio Publishing Company
ROBINSON, LOUIS G., M.E., 4th and Park Aves., Newport, Ky.	
ROCKHOLD, KENNETH EDWARD, B.S., Zanesville, Ohio	L. E. Rodgers Engineering Company
RODGERS, EBEN, Alton, Ill.	Secretary and Treasurer, Alton Brick Company
ROESSLER, FRANZ, 39 High St., Perth Amboy, N. J.	Roessler and Hasslacher Company
ROGERS, GREGORY L., Danville, Ill.	American Refractories Company
RUSOFF, SAMUEL, Anderson, Ind.	National Tile Company
RYAN, JOHN J., B.S., Seguin, Texas	Secretary, Seguin Brick and Tile Company
SALISBURY, BERT E., 1810 W. Genesee St., Syracuse, N. Y.	President, Onondaga Pottery Company
SANDERS, JOHN W., Moundsville, W. Va.	Enameler, United States Stamping Company
SANT, THOMAS HERBERT, East Liverpool, Ohio	Secretary-Treasurer, The John Sant and Sons Company
SASSETTI, FRANK L., 4147 Van Buren St., Chicago, Ill.	
SAUNDERS, WILLIAM EDWARD, B.S., E.M., 1401 Arch St., Philadelphia, Pa.	Engineer, United Gas Improvement Company

SAXE, CHARLES WILLIAM, 276 W. Boylston St., Worcester, Mass.	Chemist, Research Laboratory, Norton Company
SCHACHTEL, S. H., CR.E., Coffeyville, Kansas	Ludowici-Celadon Company
SCHAULIN, GEORGE MARVIN, Akron, Ohio	Robinson Clay Product Company
SCHOLES, SAMUEL R., PH.D., Rochester, Pa.	Chemist, H. C. Fry Glass Company
SCHORY, VIRGIL S., CR.E., Tiffin, Ohio	Ceramic Engineer, Standard Sanitary Manufacturing Company
SCHURECHT, HARRY GEORGE, Lord Hall, O. S. U., Columbus, Ohio	United States Bureau of Mines
SCOTT, WILLIAM C., Warrior, Ala.	Superintendent, Sibley Brick Company
SEAVER, KENNETH, S.B., Pittsburgh, Pa.	Assistant General Sales Manager, Harbison-Walker Refractories Company
SEBRING, CHARLES L., Sebring, Ohio	General Manager, Sebring Pottery Company
SEWELL, SIDNEY ISAAC, B.S., CR.E., 236 Fisk St., Pittsburgh, Pa.	Laboratory Assistant, United States Bureau of Standards
SHEERER, MARY G., Newcomb Pottery Co., New Orleans, La.	Assistant Director, Newcomb Pottery
SHOEMAKER, GEORGE W., Akron, Ohio	Robinson Clay Product Company
SINCLAIR, GEORGE E., Trenton, N. J.	Secretary, Star Porcelain Company
SINCLAIR, HERBERT, Trenton, N. J.	General Manager, Star Porcelain Company
SINGER, L. P., Lincoln, Calif.	Chemist, Gladding, McBean and Company
SLOAN, ALEXANDER, B.S. (in Chem.), Cumberland, Md.	Manufacturing Chemist
SMITH, AMEDEE M., Portland, Oregon	President, Western Clay Manufacturing Company
SMITH, HARRY W., 314 Smith St., East Liverpool, Ohio	Representative, Roessler and Hasslacher Chemical Company
SMITH, JAMES M., Newcastle, Pa.	Treasurer, Shenango Pottery Company
SMITH, NORMAN G., Brunswick, Me.	Treasurer and General Manager, Maine Feldspar Company
SMITH, PERRY A., New Brighton, Pa.	Secretary, A. F. Smith Company
SOLON, ALBERT L., 195 Fremont St., San Jose, Calif.	
SOLON, MARC, Trenton, N. J.	General Manager and Secretary, Mercer Pottery Company
SPEIR, HARRY F., Cedarville, N. J.	President, New Jersey Pulverizing Company

SPRINGE, OTTO, B.S., Galesburg, Ill.	Ceramic Engineer, Purington, Paving Brick Company
SPROAT, IRA E., Dry Branch, Ga.	Ceramic Engineer, Georgia Koalin Co
SPURRIER, HARRY, 704 Sheridan Ave., Detroit, Mich.	Chemist, Jeffrey-Dewitt Company
STANGER, FREDERICK, Real Estate Trust Bldg., Philadelphia, Pa.	Sales Manager, Enterprise White Clay Company
STANGL, J. M., Dundee, Ill.	Superintendent, Haeger Potteries
STANLEY, WILLIAM W., PH.B., New Brunswick, N. J.	Wasson Piston Ring Co
STAPLER, WALTER S., Stevens Pottery, Ga.	General Manager, Stevens Brothers and Company
STAUDT, AUGUST, Perth Amboy, N. J.	President, Perth Amboy Tile Works
STEINHOFF, FREDERICK LOUIS, 50 E. Green St., Champaign, Ill.	Student in Ceramic Engineering, University of Illinois
STEINMAYER, R. A. J., B.S., La Salle, Ill.	La Salle Pressed Brick Company
STERN, NEWTON W., 67 New Montgomery St., San Francisco, Calif.	Secretary and Treasurer, Pacific Porcelain Ware Company
STEVENS, DOUGLAS, F., M.E., Cayuga, Indiana	Superintendent, Acme Brick Company
STEVENSON, WILLIAM G., Oregon, Ill.	Secretary-Treasurer, National Silica Company
STOCKTON-ABBOTT, LYLE, Hotel Plaza, Port Arthur, Texas	Engineer
STONE, CHARLES, A., 1246 N. Kedzie Ave., Chicago, Ill.	Student, University of Illinois
STOWE, CHARLES BROWN, Cleveland, Ohio	President, National Fire Brick Company
SULLIVAN, EUGENE C., PH.D., Corning, N. Y.	Chief Chemist, Corning Glass Works
SWALM, PHAON H., Trenton, N. J.	Assistant Superintendent, Trenton Fire Clay and Porcelain Company
SWEELY, BURTON T., B.S., (in Cer.), Ames, Iowa	Ceramic Engineering Department, Iowa State College
TAMLYN, WALTER IRVING, E.E., 359 Crown St., Brooklyn, N. Y.	Assistant Engineer with Ralph D. Mershon
TATTON, JOSEPH, 59 Southard St., Trenton, N. J.	Trenton Potteries Company
TAYLOR, ROYAL W., 707 Twelfth St., N. W., Canton, Ohio	Assistant Secretary and Chemist, The Canton Stamping and Enameling Company
TEFFT, CHARLES FORREST, B.S.,(in Cer.). Darlington, Beaver Co., Pa.	Manager, Darlington Clay Products Company

THOMAS, CHAUNCEY R.,
2336 San Pablo Ave., Berkeley, Cal.

THOMAS, GEORGE E., General Superintendent, Highlands Fire Clay Company
St. Louis, Mo.

THOMAS, JAMES RAY, B.S., (in E.E.), Manager, Standard Brick Company
Crawfordsville, Ind.

THOMPSON, DALE D., Treasurer, C. C. Thompson Pottery Company
East Liverpool, Ohio

THRALL, CHARLES U., Superintendent, Atlantic Terra Cotta Company
1170 Broadway, New York, N. Y.

THWING, CHARLES BURTON, PH.D., President, Thwing Instrument Company
3339 Lancaster Ave., Philadelphia, Pa.

TILLOTSON, EDWIN W., JR., B.A., PH.D., University of Pittsburgh
Pittsburgh, Pa.

TILTON, EARL MONROE, CR.E., Pittsburgh Testing Laboratory
Pittsburgh, Pa.

TIMMERMAN, WALTER F., Vice-President, Western Terra Cotta Company
Kansas City, Kansas

TONE, FRANK J., Works Manager, Carborundum Company
Niagara Falls, N. Y.

TOWNSEND, EVERETT, General Manager, Robertson Art Tile Company
314 Bellevue Ave., Trenton, N. J.

TRAUTWEIN, J. O., President, Trautwein Dryer and Engineering Company
417 S. Dearborn St., Chicago, Ill.

TREISCHEL, CHESTER, B.S., Kankakee Brick and Tile Company
Kankakee, Ill.

TRUMAN, GAIL R., Ceramic Chemist, St. Louis Terra Cotta Company
5801 Manchester Ave., St. Louis, Mo.

TURNER, A. M., M.E., Superintendent and Treasurer, Scioto Fire Brick Company
Sciotoville, Ohio

VAN SCHOICK, ELMER HOLMES, B.S., (in Cer.), Chicago Retort and Fire Brick Company
Box 166, Ottawa, Ill.

VODREY, WILLIAM E., General Manager, Vodrey Pottery Company
East Liverpool, Ohio

VOLLKOMMER, JOSEF, President and Manager, The Vitro Manufacturing Company
Bessemer Bldg., Pittsburgh, Pa.

VOLZ, WILLIAM J., Superintendent Evens and Howard Fire Brick Company
St. Louis, Mo.

WAGNER, C. L., B.S., C.E., Chief Chemist, Superior Portland Cement Company
Seattle, Wash.

WAGNER, FRITZ, Vice-President and Treasurer, The Northwestern Terra Cotta Company
1000 Clybourn Ave., Chicago, Ill.

WALDEN, ALBERT S., Foreman, National Carbon Company
Cleveland, Ohio

WALDUCK, CHARLES LOUIS, B.S., Superintendent, Grueby Faience and Tile Company
Boston, Mass.

WALKER, CHARLES HENRY, 400 W. 4th St., East Liverpool, Ohio	Assistant Superintendent, Homer Laughlin China Company
WASHBURN, EDWARD W., S.B., PH.D., Urbana, Ill.	Professor of Ceramic Chemistry, University of Illinois
WEGENER, HARVEY A., CR.E., East Pittsburgh, Pa.	Commercial Engineer, Supply Department, Westinghouse Electric and Manufacturing Company
WEIGEL, CHARLES, Hebron, North Dakota	President, Hebron Fire and Pressed Brick Company
WEIL, EDGAR H., B.S., Cleveland, Ohio	Vitreous Enameling Company
WELLS, HARRY B., Canton, Ohio	Superintendent, The Belden Brick Company
WHITAKER, FRED A., Keasbey, N. J.	Superintendent, General Ceramics Company, Plant No. 1
WHITE, RAY HILL, A.B., S.B., Niagara Falls, N. Y.	Research Engineer, Norton Company
WHITEHEAD, RALPH R., M.A., Woodstock, Ulster Co., N. Y.	"Byrdcliffe" Pottery
WHITELAW, JAMES CAMERON, B.S., 1220 Boren Ave., Seattle, Wash.	
WHITFORD, WILLIAM GARRISON, PH.B. (in Cer.), Chicago, Ill.	Instructor in Design and Ceramic Art, University of Chicago
WHITMER, J. D., CR.E., 9 Ball St., Zanesville, Ohio	American Encaustic Tile Company
WIGFIELD, CLAUDE LAWRENCE, 205 E. 2nd St., Elyria, Ohio	Enameler, The Elyria Enameled Products Company
WILDER, THOMAS MILTON, Ravinia, Ill.	Proprietor, Wildwood Shop
WILL, OTTO W., Perth Amboy, N. J.	Superintendent, Color Department, Roessler and Hasslacher Chemical Company
WILSON, HEWITT, CR.E., Auburn, Washington	Ceramic Chemist, Northern Clay Company
WOODS, WILLIAM J., A. B., Lewistown, Pa.	Assistant General Manager, Pennsylvania Pulverizing Company
WORTH, S. HARRY, 706 Franklin Bank Bldg., Philadelphia, Pa.	President, Pennsylvania Feldspar Company
WRIGHT, JOSEPH WILLIAM, 523 E. Green St., Champaign, Ill.	Student, Ceramic Engineering, University of Illinois
YATES, ALFRED, Shawmut, Elk Co., Pa.	General Manager, Shawmut Paving Brick Company
YEARSLEY, HOWARD L., 133 Westmont Ave., Haddonfield, N. J.	Manager, Electric Porcelain and Manufacturing Company
YOUNG, GEORGE F., Zanesville, Ohio	Manager, Roseville Pottery Company
YOWELL, JOHN BENNETT, B.S., Dudley, Ill.	

ZIMMERLI, WM. F., B.S., PH.D., Rochester, N. Y.	Chemist, Pfaudler Co
ZOPFI, ALBERT S., Toledo, Ohio	Secretary and Treasurer, Buckeye Clay Pot Company
ZWERMANN, CARL H., Kalamazoo, Mich.	President and General Manager, Kalamazoo Sanitary Manufacturing Company

RULES OF THE SOCIETY

[Revised 1915]

I

OBJECTS

The objects of the American Ceramic Society are to promote the arts and sciences connected with ceramics by means of meetings for the reading and discussion of professional papers, the publication of professional literature, and for social intercourse.

II

MEMBERSHIP

The Society shall consist of Honorary Members, Active Members, Associate Members and Contributing Members.

Honorary members must be persons of acknowledged professional eminence, whom the Society wishes to honor in recognition of their achievements in ceramic science or art. Their number shall at no time exceed two percent of the combined active and associate membership.

Active members must be persons competent to fill responsible positions in ceramics. Only Associate Members shall be eligible to election as Active Members, and such election shall occur only in recognition of attainments in the field of ceramics, and interest in the Society, as evidenced by papers or discussions contributed to its meetings.

Associate Members must be persons interested in ceramics or allied arts.

Contributing Members must be persons, firms, or corporations who, being interested in the Society, make such financial contributions for its support as are prescribed in Section 3.

Honorary Members shall be nominated for election by at least five active members, and approved by the Board of Trustees. Their nomination shall be placed before the Society at an annual meeting, and to be elected they must receive the affirmative vote of at least 90 percent of those voting, by letter ballot, at the next succeeding annual meeting.

To be promoted to active membership, Associate Members must be nominated in writing by an Active Member, and must be seconded by not less than two other Active Members, and must be approved by the Board of Trustees. Their nomination shall be accompanied by a statement of their professional qualifications and a list of their publica-

tions, if any. Their nominations, when approved by the Board of Trustees, shall be placed before the Society at an annual meeting, and to be elected they must receive the affirmative vote of not less than 75 percent of those voting, by letter ballot, at the next succeeding annual meeting.

A candidate for Associate Membership must make application upon a form, prepared by the Board of Trustees, which shall contain a written statement of the age and professional experience of the candidate, and a pledge to conform to the laws, rules and requirements of the Society. Such applications must be endorsed by two Active Members of the Society as sponsors, and must be approved by the Board of Trustees. The Board may act by letter ballot upon such application at any time, after which an approved candidate may be enrolled on the proper list of the Society upon payment of the fees and dues prescribed in Section 3.

Contributing Members shall be nominated by an Active Member, and approved by the Board of Trustees, and may be enrolled on the proper list of the Society at any time upon payment of the dues prescribed in Section 3.

All Honorary Members, Active Members, Associate Members, and Contributing Members shall be equally entitled to the privileges of membership, except that only Active Members shall be entitled to vote and hold office. The roster of each grade of membership shall be printed separately, in at least one publication issued by the Society annually. Any person may be expelled from any grade of the membership of the Society if charges signed by five or more active members are filed against him, and a majority of the Board of Trustees examines into said charges and sustains them. Such person, however, shall first be notified of the charges against him, and be given a reasonable time to appear before the Board of Trustees, or present a written defense, before final action is taken by the Board of Trustees.

III

DUES

Honorary Members shall be exempt from all fees or dues.

The initiation fee of Active Members shall be ten dollars, and if not paid within three months after the date of their election, the latter shall be null and void. The annual dues for Active Members shall be fixed by the Board of Trustees, and shall not exceed ten dollars.

The initiation fee of Associate Members shall be five dollars, and their annual dues shall be fixed by the Board of Trustees, but shall not exceed five dollars. The privileges of Associate Membership after election shall begin upon payment of the initiation fees, and dues for the first year.

Contributing Members shall pay no initiation fee into the Society. Their annual dues shall be fixed by the Board of Trustees, but shall not exceed twenty-five dollars. The privileges of membership shall begin upon payment of the annual dues.

Any Active Member or Associate Member in arrears for over one year may be suspended from membership by the Board of Trustees, until such arrears are paid, and in event of continued dereliction, may be dropped from the rolls. Active Members in arrears are not eligible to vote. The annual dues of Active and Associate Members are payable within three months succeeding date of annual meeting.

IV

OFFICERS

The affairs of the Society shall be managed by a Board of Trustees, consisting of a President, Vice-President, Secretary, Treasurer and three Trustees, who shall be elected from the Active Members at the annual meeting, and hold office until their successors are elected and installed.

The President, Vice-President, Secretary and Treasurer shall be elected for one year, and the Trustees for three years; and no President, Vice-President, or Trustee shall be eligible for immediate re-election to the same office.

The duties of all officers shall be such as usually pertain to their offices, or may be delegated to them by the Board of Trustees or the Society; and the Board of Trustees may, at its discretion, require bonds to be furnished by the Treasurer.

Vacancies in any office shall be filled by appointment by the Board of Trustees, but the new incumbent shall not thereby be rendered ineligible to re-election at the next annual meeting to the same office. On the failure of any officer to execute his duties within a reasonable time, the Board of Trustees, after duly warning such officer, may declare the office vacant, and appoint a new incumbent.

A majority of the Board of Trustees shall constitute a quorum, but the Board of Trustees shall be permitted to carry on such business as it may desire by letter.

V

ELECTIONS

At the annual meeting, a Nominating Committee of five Active Members, not officers of the Society, shall be appointed, and this committee shall send the names of the nominees to the Secretary at least sixty days before the annual meeting who shall immediately forward the same to the Active Members. Any other five Active Members may act as a self-constituted Nominating Committee, and also present the

names of any nominees to the Secretary, provided it is done at least thirty days before the annual meeting. The names of all nominees provided their assent has been obtained, shall be placed on the ballot without distinction as to nomination by the regular or self-constituted Nominating Committee, and shall be mailed to every member, not in arrears, at least twenty days before the annual meeting. The ballot shall be enclosed in an inner blank envelope, and the outer envelope shall be endorsed by the voter, and mailed to the Secretary. The blank envelopes shall be opened by three scrutineers appointed by the President, who will report the result of the election at the last session of the annual meeting. A plurality of votes cast shall elect.

VI

MEETINGS

The annual meeting shall take place on the first Monday in February, or as soon thereafter as can be conveniently arranged, at such place as the Board of Trustees may decide, at which time a report shall be made by the Board of Trustees, Treasurer and scrutineers of election, and the accounts of the Treasurer shall be audited by a committee of three, appointed by the President. Ten Active Members shall constitute a quorum at any regular meeting, and a majority shall rule unless otherwise specified.

The order of business at the annual meeting shall be:

1. President's address.
2. Reading of minutes of last meeting.
3. Reports of the Board of Trustees and Treasurer.
4. Appointment of committees.
5. Old business.
6. New business.
7. Reading of papers.
8. Announcement of election of officers, Honorary and Active Members.
9. Installation of officers and new members.
10. Adjournment.

Other meetings may be held at such time and places during the year as the Board of Trustees may decide, but at least twenty days' notice shall be given of any meeting.

The President shall appoint at the annual meeting a committee of five, to be known as the Summer Meeting Committee, whose duty it shall be to arrange for a summer excursion meeting at some suitable point. The expenses of the Summer Meeting Committee in arranging the program of visits and for printing, rooms and facilities for meetings, shall be borne by the Society.

VII

PUBLICATIONS

The Board of Trustees shall employ, at suitable compensation, an Active Member of the Society as Editor of its publications. The Editor, together with the Secretary and Treasurer, shall constitute a Publication Committee. The Publication Committee shall provide for the publication of an annual volume, entitled "Transactions of the American Ceramic Society." This volume shall contain a list of the officers, a list of members of the Society, classified into grades, a list of the ex-Presidents, the dates and location of meetings, the annual report of the Board of Trustees and Treasurer, the list of prices of the publications of the Society, the rules of the Society, and any other matter pertaining to the business administration of the Society that the Publication Committee may think proper. It shall also contain such of the papers and discussions thereon as the Publication Committee may consider desirable, and each volume shall contain a list of the papers and discussions and an index. The volume shall be six inches wide by nine inches long, and part of the issue shall be bound in paper covers, and part in cloth binding. The quality of the paper, the kind of type, the illustrations, and all other mechanical details of the printing and publishing of the books or reprints shall be in the hands of the Publication Committee, subject to the control of the Board of Trustees.

The acts and policies of the Publication Committee shall at all times be subject to the examination and approval of the Board of Trustees, but the Board shall be bound by contracts entered into by the Publication Committee in the name of the Society. The Publication Committee shall have full power and authority to decide what papers and discussions to publish, which discussions shall be germane to the subject matter, and in what order they shall be published, and in what manner and to what extent they shall be illustrated. In event that the Board of Trustees shall undertake the publication of some other matter or book than the Transactions, the Publication Committee shall act in the same capacity for that publication as in the publication of the annual volume of the Transactions.

One copy of the paper-bound edition of the Transactions shall be sent prepaid to each member of the Society not in arrears. Members desiring cloth-bound copies will be furnished them in place of the paper-bound copy at an increased cost for the binding. No member shall be furnished more than one copy of the Transactions free for any single year. Members cannot purchase extra copies of the Transactions at less than the current commercial rates. A member shall be permitted to purchase one complete file of the publications of the Society at less

than the current commercial rate, the amount to be fixed by the Publication Committee and called the Member's rate.

The Secretary shall have the custody of all publications of the Society, shall keep them safely stored and insured, and shall sell these volumes to the public at prices which shall be fixed by the Publication Committee for each new volume as issued. The Publication Committee shall also, from time to time, fix the price of the old volumes remaining unsold, and shall have authority to refuse to sell the old volumes of the Transactions except in sets, at such time as the quantity remaining of any number becomes so small, as in their judgment to warrant such action.

The Editor shall request the author of each article appearing in the Transactions of the Society to fill out and sign, within a definite time limit, a blank form, specifying the number of reprints of said article, if any, which he desires. This form shall contain a table from which can be computed the approximate cost at which any reprints will be furnished. In event that the expense of furnishing the desired number of reprints is large, the Publication Committee may require the author to pay in advance for part or all of the cost involved before the publication of the reprints is begun. On receipt of such signed order within the time limit set, the Editor shall cause to have printed the desired number of copies. If the author makes no reply, or replies after the time limit has expired, then the Society will not be responsible for the publication of any reprints of the article in question, except at the usual market price for the printing of new matter.

No one shall have the right to demand the publication of an article independent of the discussion which accompanied it, and no one having taken part in a discussion upon an article shall be entitled to order reprints of the discussion separately and apart from the article itself.

The Society is not, as a body, responsible for the statements of facts or opinions expressed by individuals in its publications.

VIII

PARLIAMENTARY STANDARD

Robert's "Rules of Order" shall be the parliamentary standard on all points not covered by these rules.

IX

AMENDMENTS

To amend these rules, the amendment must be presented, in writing, at the annual meeting of the Society, and must be printed on the ballot for officers and sent out not less than twenty days in advance of the next annual meeting, and if the said letter ballot shows an

affirmative vote of not less than two-thirds of the total vote cast, then the same shall be declared carried.

X

LOCAL SECTIONS

Designation. Local sections, each carrying some distinguishing title prefixed to the words "Section of the American Ceramic Society," may be authorized by the Society.

Purpose. The purposes of such sections shall be to strengthen and extend the work of the Society as defined in Section I of its Rules, by more frequent meetings in local centers than are possible to the Society as a whole, and by bringing the benefits of the work to persons who would not otherwise be reached.

Granting of Charters. Application for permission to form a local section must be in writing and signed by not less than ten members of the Society in good standing, residing in the general locality where the section is to be formed, of whom one at least shall be an Active member. To be considered at any given meeting, an application must be filed with the secretary at least 30 days prior to the date of the meeting, and notice that the application is pending must appear in the program of the meeting. To be granted, the application must receive the affirmative vote of two-thirds of those present. In event of affirmative action, the Society will issue a charter to the applicants, authorizing them to form a section under the name proposed. Charters for local sections may be temporarily suspended by the Board of Trustees for cause, but no charter can be permanently rescinded, except by vote of two-thirds of those present at a regular meeting of the Society after due publication in the program of the meeting that the matter is pending.

Legislative Powers. Local sections shall have power to make their own rules and by-laws, except that they shall not pass any rule or by-law which is in conflict with the Rules of the Society.

Officers. The Officers of local sections shall be a Chairman, a Secretary and a Councilor, and such others as the Section may prescribe. The duties of the Chairman and Secretary shall be such as usually pertain to those offices. The Councilor must be an Active member of the Society, and it shall be his duty to advise the Section in all matters pertaining to its relations with the Society, and to make an annual report to the Society regarding the work and status of the Section. The names of the Chairman, Secretary and Councilor of each Section shall appear in the roster of the Society in the Annual Volume of the Transactions of the Society.

Eligibility. Only members of the Society shall be eligible to full participation in the work of local Sections, but Sections may provide in their by-laws for a limited participation in their work by persons

not members of the Society, when in their opinion the purposes of the Society will be subserved by such a course, provided always that such persons shall not vote or hold office in the Section.

Finances. Local Sections shall have power to fix their own dues or assessments, such dues or assessments being in addition to and independent of the regular dues and assessments of the Society upon its members. No Section shall have authority to incur debt in the name of the Society or for which the Society may become liable.

XI

STUDENT BRANCHES

Designation. Student Branches, each carrying some distinguishing title prefixed to the words "Student Branch of the American Ceramic Society," may be established in Institutions in which regular courses of instruction in Ceramics are maintained.

Purpose. The purposes of such Student Branches shall be to strengthen and extend the work of the Society, as defined in Section 1 of the Rules, by enlisting the interest and support of students of Ceramics while still in schools, and by stimulating the spirit of ceramic research among them.

Granting of Charters. Application to form a Student Branch in any institution must be in writing, and signed by not less than five regularly enrolled students in good standing and endorsed by two or more members of the Society. The application must be filed and acted upon as provided for Local Sections in Section X, and may be suspended or revoked for cause in the same manner.

Legislative Powers. Student Branches shall have power to make their own rules and by-laws, except that they shall not pass any rule or by-law in conflict with the Rules of the Society.

Officers. The officers of Student Branches shall be a Chairman, a Secretary, a Councilor, and such others as the Student Branch may prescribe. The Chairman and Secretary shall be elected by the Student Branch, and their duties shall be such as usually pertain to these offices. The Councilor shall be an active member of the Society, appointed by the Board of Trustees to act in this capacity to the Student Branch. The duties of the Councilor shall be to advise the Student Branch in all matters pertaining to its relations to the Society and to make an annual report to the Society regarding the work and status of the Student Branch. The names of the Chairman, Secretary and Councilor for each Student Branch shall appear in the Roster of the Society in the Annual Volume of the Transactions.

Eligibility. Membership in a Student Branch shall be limited to the instructional force and regularly enrolled students of schools in which branches are located, subject to the rules of the school concerned governing outside activities of students.

Finances. Student Branches shall have power to fix their own dues and assessments, and as such shall pay no dues or initiation fees to the Society. No Student Branch shall have authority to incur debt in the name of the Society or for which the Society may become liable.

Relation of Parent Society. Members of a Student Branch as such shall pay no dues or initiation fees to the Society, but upon depositing a certificate of good standing from their Secretary may purchase from the Society its Transactions at the same rate as Associate members of the Society. This privilege shall cease when the student's connection with the school ceases, but members of a Student's Branch upon leaving school may at once become associate members of the Society, by depositing their certificates, making the proper application, and paying the regular initiation fee.

PUBLICATIONS

The following is a list of the volumes published by the Society and the prices at which they are for sale to the general public:

Description of volume.			Bound in paper.	Bound in cloth.
Vol. I.	1899,	110 pages.....	$4.00	$4.75
Vol. II.	1900,	278 pages.....	4.00	4.75
Vol. III.	1901,	238 pages.....	4.00	4.75
Vol. IV.	1902,	300 pages.....	4.00	4.75
Vol. V.	1903,	420 pages.....	5.00	5.75
Vol. VI.	1904,	278 pages.....	4.00	4.75
Vol. VII.	1905,	454 pages.....	4.00	4.75
Vol. VIII.	1906,	411 pages.....	4.00	4.75
Vol. IX.	1907,	808 pages.....	5.00	5.75
Vol. X.	1908,	582 pages.....	5.00	5.75
Vol. XI.	1909,	632 pages.....	5.50	6.25
Vol. XII.	1910,	882 pages.....	5.50	6.25
Vol. XIII.	1911,	837 pages.....	5.50	6.25
Vol. XIV.	1912,	888 pages.....	5.50	6.25
Vol. XV.	1913,	747 pages.....	5.50	6.25
Vol. XVI.	1914,	611 pages.....	5.50	6.25
Vol. XVII.	1915,	815 pages.....	*....	6.25
Vol. XVIII.	1916,	947 pages.....	....	6.25
Vol. XIX.	1917,	pages.....	....	6.25
Complete Set			$76.00	$106.75

* Volume XVII and all following Volumes will be bound in cloth only.

The Board of Trustees established in the beginning a differential between members of the Society and others, in the matter of prices to be paid for copies of the Proceedings. This differential has been changed from time to time as volumes have grown scarcer and sales increased. The present arrangement, which will stand until March 1, 1915, allows a straight discount of 40 percent to members in good standing. Members in arrears are not furnished copies of the volume for the current year, nor allowed the discount for the older publication. Members are also not permitted to purchase more than one full set of the publications at members' rates. The care and sale of the Publications has been transferred to the Publication Committee, which

reserves the right to change the discount from time to time on any one volume or on all, as may be necessary.

The number of copies of the earlier volumes is not large, and members are advised to procure full sets as soon as possible. The prices will never be less and will certainly rise as time goes on.

In addition to the above volumes of the Transactions, the Society has also published the following books, which will be sold *net* at the prices listed to the public and members alike:

The Collected Writings of Dr. Hermann August Seger, Volume I. Contains (*a*) Treatises of a General Scientific Nature. (*b*) Essays Relating to Brick and Terra Cotta, Earthenware and Stoneware, and Refractory Wares. Pages, 552. Bound in cloth	$7.50
The Collected Writings of Dr. Hermann August Seger, Volume II. (*b*) Essays on White Ware and Porcelain. (*c*) Travels, Letters and Polemics. (*d*) Uncompleted Works and Extracts from the Archives of the Royal Porcelain Factory. Pages, 605. Bound in cloth	7.50
A Bibliography of Clays and the Ceramic Arts, by Dr. John C. Branner, 1906, 451 pages. Bound in cloth. Contains 6027 titles of works on Ceramic subjects	2.00

The above publications will be shipped at the consignee's expense, by express, to any address on receipt of the price. All checks or money orders should be made payable to the American Ceramic Society, and not to the Secretary or the Treasurer.

EDWARD ORTON, JR.,
Secretary.

Columbus, Ohio.

ANNUAL REPORT OF THE BOARD OF TRUSTEES

To the Members of the American Ceramic Society: —

The Board of Trustees has prepared the following statement of the business and condition of the Society for the period Feb. 1st, 1916, to Feb. 1st, 1917.

MEMBERSHIP

There has been some growth. The total accessions this year, 79, are greater than usual, but the losses, 58, are also higher, so that the net gain of 21 is not materially different from usual. In view of the disturbed conditions abroad, which have also reacted here, the showing is thought to be a good one. The analysis follows:

Brought Forward February 1st, 1916

Honorary members	4
Contributing members	2
Active members, resident	63
Active members, foreign	11
Associate members, resident	392
Associate members, foreign	44
Total	516
Brought forward	516

Accessions During the Year

Active members, resident	11
Associate members, resident	58
Associate members, foreign	10
Total accessions	79

Losses During the Year

Contributing members	2
Active members, resident, by death	2
Active members, resident, non-payment of dues	1
Active members, foreign, by transfer to resident	1

Active members, foreign, non-payment of dues	5
Associate members, resident, by transfer to active	10
Associate members, resident, by resignation and non-payment of dues	26
Associate members, foreign, by transfer to resident	3
Associate members, foreign, by resignation and non-payment of dues	8
Total losses	58
Net gain	21
Total February 1, 1917	537

Status February 1st, 1917

Honorary members	4
Active members, resident	71
Active members, foreign	5
Associate members, resident	414
Associate members, foreign	43
Total	537

FINANCIAL STATEMENT

The amount of cash carried forward, $1,489.12 shows a gain of $429.21 over the balance brought forward Feb. 1st, 1916. This showing is a little better than the real facts warrant, in that there is an unpaid balance on the printing of Volume XVIII, not yet settled. This amount is about $105.00, so that a substantial gain in resources remains.

The analysis of receipts and expenditures follows:

RECEIPTS

Brought forward February 1st, 1916	$1,059.91	$1,059.91
Receipts from Dues:		
Active members, 1916 dues	506.91	
Associate members, 1916 dues	2,125.03	
Collection of dues in arrears	264.50	
Payments of dues made in advance	45.50	2,941.94
Receipts from Initiation Fees:		
From active members	85.00	
From associate members	300.00	385.00

Receipts from Sale of Publications:		
From Transactions	1,011.50	
From Branner Bibliography	2.00	
From sale of Seger's Collected Writings	28.25	
From reprints	182.47	1,224.22
Total		$5,611.07
Receipts brought forward		$5,611.07

DISBURSEMENTS

Publication of Volume XVIII:		
Stenographic report	$155.00	
Drawings, illustration and engravings	550.18	
Printing, binding and casing	1,465.59	
Editor's salary ($600) and expenses ($11.11)	611.11	2,781.88
Expenses of delegates to meeting of Committee on Publication	27.65	
Reprint of article for author	4.00	31.65
Paid for Administration:		
Salary for Assistant Secretary	300.00	
Extra clerk hire	139.25	
Postage, stationery and supplies	202.50	
Insurance and storage on society's property	55.50	
Telegraph and telephone	3.96	
Transportation of publications (express and mail)	327.03	
Binding and casing early volumes	35.00	
Expense of convention including Section Q	213.48	
Check returned on account of no funds	5.00	
Refund of overpaid dues	5.00	
Expenses of Summer meeting Committee	21.70	1,308.42
Total		$4,121.95
Cash balance in bank		1,489.12
Total		$5,611.07

The expenses of publication are slightly higher this year, and the outstanding account due, and chargeable to this item, would bring the total still higher. The indications are that increased cost of paper, and practically everything else, will make a considerable increase again necessary for the ensuing volume.

The Expenses of Administration have increased about $100.00, largely due to the assumption by the Society of binding and Section Q expenses. The expenses have been kept well within the income and there is no ground for doubt that the Society will be able to stand the increased cost of these abnormal times, without serious inroad upon its reserve, or change of its financial policy.

PUBLICATIONS

The sale of publications has shown some gratifying tendencies. The gross sales are better than in any recent year, and the sales of the current year's volume, and last year's volume are markedly higher than ever before. There is a reduction in the number of sales of complete sets, which is natural. The amount of literature on hand remains a little less than a year ago, as shown.

Publications

VOLUME NUMBER.	NUMBER REMAINING ON HAND FEB. 1ST, 1916.	RECEIVED SINCE.	SALES.	EXCHANGES	NUMBER ON HAND FEB. 1ST, 1916. BOOK ACCOUNT.
I	144	...	8	...	136
II	102	...	10	...	92
III	141	...	7	...	134
IV	116	...	7	...	109
V	82	...	8	...	74
VI	111	...	11	...	100
VII	119	...	9	...	110
VIII	99	...	5	...	94
IX	62	...	3	...	59
X	95	...	10	...	85
XI	130	...	5	...	125
XII	81	...	8	...	73
XIII	181	...	6	...	175
XIV	99	...	10	...	89
XV	129	...	11	...	118
XVI	176	...	14	...	162
XVII	218	...	82	...	136
XVIII	...	750	551	20	179
Branner Bibliography	751	...	7	...	744
Totals	2836	750	...	20	2788

SUMMER SESSION

A very satisfactory summer session was held August 23-24-25 at St. Louis, Mo., participated in by about fifty persons, forty members and ten guests. The weather was perfect, and arrangements by the efficient local committee were carefully carried out.

The Itinerary was as follows:

Wednesday, A. M.

Plant of the Mississippi Glass Company, where the manufacture of figured window glass, and wire glass was shown. Plant of the Walsh Fireclay Produce Company, Manufacturing glass house refractories, and general refractories.

Wednesday, P. M.

Plant No. 3 of the Hydraulic Press Brick Company, manufacturing rough texture face brick. Plant No. 11, same company, making vertical fiber paving brick. Plant No. 5, same company, making dry-pressed common brick, and biscuit brick for enameling. The Enamel Brick plant same company, making glazed and enameled face brick.

Thursday, A. M.

Evans' and Howard's Manchester Avenue Plants, making fire brick, fireclay goods, and a general line of construction materials. St. Louis Terra Cotta Company's Plant, making plain and glazed architectural terra cotta.

Thursday, P. M.

Luncheon at the Laclede-Christy Clay Products Company's offices, followed by visit to their works. Party divided at this point, part of them going to the Winkle Terra Cotta Company's Plant, and the others through the Laclede-Christy Testing Laboratory. Reunited, the party went through the Blackmer and Post Sewer Pipe Company's plant, where large sized sewer pipe are the specialty, and lastly through the Parker-Russell Mining and Manufacturing Company's plant, making refractory materials for gas works, smelters, and the general trade.

Friday.

The party went by river steamer to Alton, Illinois, and inspected the large plant of Mr. Eben Rogers, manufacturing paving brick, with continuous kiln. A local strike prevented the last visit of the day. The party broke up on arrival in St. Louis.

The evenings were spent by the party in dining together, and later visiting the theater or amusement parks. All reports indicate the whole occasion as most successful and profitable for all who attended.

STUDENT BRANCHES

Two more Student Branches have been formed, one at the University of Illinois, and one at the Iowa State College. In both instances, the occasion was made a somewhat formal one. President Barringer installed the Illinois Branch, and Professor Bleininger performed the same service for the Iowa Branch.

The reports of the councillors of these branches, and the others, will be found in the appropriate place in the proceedings. The propriety and advantage to the Society, and to all concerned, of establishing sections of the Society at other Ceramic centers, should be considered by the Society.

COMMITTEE ON RULES GOVERNING PUBLICATIONS

As the result of some discussion in the Society, a committee was appointed at the last meeting to consist of the Publication committee and two others to be appointed by the Chair, to consider the subject of the publications of the Society, and to formulate such added regulations or rules for the guidance of members in submitting contributions, or for the editor in preparing them for publication, and with instructions to prepare a written report prior to the publication of another Volume of the Transactions. The Publication Committee consisted of Edward Orton, Jr., Secretary, Herford Hope, Treasurer, Arthur S. Watts, Editor, and Messrs. Ellis Lovejoy and A. V. Bleininger were appointed as the two other members.

This committee held a meeting at Columbus, Ohio, in the

latter part of March, 1916, and formulated a report, which was duly presented to the Board of Trustees, April 6th, and was approved by them, April 15th, and ordered printed and distributed, which has been done, in Circular No. 4, Series 18, dated April, 1916.

By this report, Rule VII is not altered or amended, but a considerable mass of additional matter has been added in the form of regulations, which may be changed by vote of the Society, without the formality of amending the rules. These regulations put the matter of publication and editing upon a much clearer basis than ever before, and should result in improved work. No piece of committee work undertaken by the Society has ever been put through in more effective way than this.

ASSOCIATE MEMBERSHIP AS PRIZES

During the current year, The Brick and Clay Record, of Chicago, through their editor, organized a competition among students in Ceramic Schools for the best articles upon Ceramic Subjects, the same to be judged by a committee, who should not know the identity of the writers of the respective papers. As a result, six papers were submitted, and judged, and the two winners were awarded money to cover their initiation fees and one year's dues in this Society. The winners both filed their applications and have been duly admitted as Associate members. Their names are:

Earl E. Lebman, Peoria, Ill.
B. T. Sweely, Ames, Iowa.

The desirability of this same practice being taken up by firms, local sections, ceramic fraternities, or groups of any kind seems clear, and it is hoped will lead to future gains in membership, and in growth of interest in the subject.

CONCLUSION

The work of the Society is in a flourishing condition. Its membership is at the highest point. Its financial strength was

never greater. Its publication was never larger and better, and the spirit and enthusiasm of the membership seems good.

Respectfully submitted,

For THE BOARD OF TRUSTEES,

EDWARD ORTON, JR., *Sec.*

REPORT OF BEAVER SECTION

ERNEST MAYER, COUNCILOR.

Regular meeting was held April 13th, 1916, at Brighton Club, New Brighton, Pa.

Mr. R. R. Hice gave a resume of the papers read at the Eighth Annual meeting of American Ceramic Society held at Cleveland, Feb. 21-24, 1916.

The following subjects were taken up and discussed very thoroughly, Sagger, Wash, and Coal suitable for Kiln Firing. Attendance at the meeting 14.

Meeting June 22nd, 1916, at 8 P. M., Brighton Club, New Brighton, Pa., twelve persons present, 2 from Pittsburgh, 2 from East Liverpool and 1 from New Castle.

Mr. A. V. Bleininger of the Bureau of Standards read a most interesting paper on "The Properties of Some European Bond Clays". An interesting discussion followed the address.

A discussion on effect of substituting Quartz for French Flint brought out some very interesting information.

Meeting held at Brighton Club, New Brighton, Pa., Nov. 9th, 1916, at 8:30 P. M., 10 persons present.

The following officers were elected:

F. W. Walker, Jr.....Chairman
F. McDonald.....Vice Chairman
H. Hope .....Secretary
W. S. Mayer.....Treasurer
E. Mayer .....Councilor

The address of the evening was by Mr. R. R. Hice on "Coal for Kiln Burning" from which valuable information was obtained.

Regular meeting was held January 18th, 1917, at Brighton Club, New Brighton, Pa., 12 persons present.

There was discussion on the following subjects: "Appliance for Elimination of Manual Labor in Reference to Stove Rooms",

"The Best Methods of Charging Large Ball Mills Used for Body Grinding", and a very interesting discussion on Pyrometersan Iron Constantan Couple as used by Bureau of Standards give great promise of usefulness.

REPORT OF OHIO STATE UNIVERSITY STUDENT BRANCH

ARTHUR S. WATTS, COUNCILOR.

For the Ohio State Student Branch, I desire to report a very flourishing condition. We have forty-six active members. The freshmen students not being registered as ceramic engineers do not become eligible for membership. The following meetings were held during the present school year:

Oct. 10—Reception to new members and election of officers.

Nov. 22—Talk by H. L. Longenecker on "High Speed Kilns".

Dec. 19—Talk by T. W. Garve on "Richardson Producer Gas Fired Continuous Kiln".

Jan. 16—Talk by Ellsworth Ogden on "The Continuous Car Kiln of the Scott Process Company".

Feb. 13—Annual Pig Roast in Department Hall. Toast by Professor Edward Orton, Jr.

March 13—Talk by Mr. L. E. Eisensmith of the American Blower Co., on "Problems Met in the Drying of Brick".

April 17—Talk by Dr. W. J. McCaughey on "The Application of the Microscope to Ceramic Problems".

May 15—Talk by Mr. Haigh on "The Haigh Continuous Kiln".

Enthusiasm is running very high at Ohio State University, chiefly because of an abnormal demand for ceramic engineers. Our recent graduates, as well as those who have been out many years, send us very encouraging reports of a constantly improving relation between the industries and the ceramic engineers.

REPORT OF NEW YORK STATE STUDENT BRANCH

CHARLES F. BINNS, COUNCILOR.

The aim of the Branch has been to arrange programs which as far as possible should be carried out by the students themselves. Members of the Faculty have been in constant attendance at the meetings but have in only a few cases taken entire charge of the proceedings.

The first meeting held in September was devoted to organization. The chairman who had been elected the previous year had decided not to return to College so that an election became necessary. Mr. Mark Sheppard, a senior, was chosen and a program committee was elected. It was decided to hold one meeting each month.

At the October meeting Mr. Ayars, a senior, gave an account of the work in which he had been engaged during the Summer. He had secured employment at the plant of the Sun Brick Company at Toronto, Canada. The production of Dennison interlocking tile was fully discussed and the speaker showed that he had made himself familiar with the details of die construction and the general processes of manufacture.

The interest aroused by this meeting was so great that the action which decided upon one meeting each month was rescinded and it was voted to hold two meetings monthly.

On October 24 Mr. Blumenthal, a member of the Junior class, gave an account of his summer practice. He had been employed by the Olean Tile Co., Olean, New York, in the manufacture of vitrified floor tile. This company was making additions to the plant so that some experience in construction was gained. Mr. Blumenthal had been assisting in the general manufacture and especially in kiln burning. Natural gas was used and the kilns were regulated by the gas pressure in a simple manometer. A brisk discussion followed the talk.

At the meeting held on November 14 there was a discussion as to the admission of lower classmen to the Society. As the Freshmen in the New York State School are regularly enrolled in ceramic engineering it was voted that all students so

enrolled be admitted as members. Prof. Shaw who had been appointed professor of Ceramic Engineering at the opening of the school year, gave a talk on the production of enamels for iron and steel.

At this time some important changes took place which greatly affected the work of the Branch. Mr. Sheppard dropped out of the course for the remainder of the year and therefore resigned from the chairmanship.

Only one meeting was held in December and on this occasion the students entered upon a lively discussion as to the course of study. Some excellent criticisms were made and these have since been taken into consideration by the Faculty.

As the Christmas vacation intervened here the next meeting was held on January 9, 1917. This was placed in charge of the Sophomore class and several interesting subjects were brought up for discussion.

At the meeting held on February 13 Prof. Binns gave an account of the dedication of the new Ceramic Building at the Illinois State University which he had attended and at which he had delivered an address. This was followed by reports on thesis work given by members of the Senior class.

The meeting on February 27 was made a symposium on cements. Mr. King spoke on oxychloride cements, Mr. Blumenthal on Portland Cements, Mr. Ayars on Natural and Pozzuolane Cements and the discussion was summed up by Prof. Shaw.

The meeting on March 13 was made a social event to which the members of the Department of Applied Arts were invited. The delegates who had attended the convention of the American Ceramic Society in New York City gave reports of the meetings and the papers which had been prepared by students and read there were given before the assembled school. Miss Saunders read her paper on "The Crawling of Matt Glazes", Miss Wells hers on "The Duplication of an Ancient Ware" and Mr. Sutton his on "The Interchange of Quartz and Flint in Pottery Bodies".

Prof. Binns summed up the meeting and gave his impressions of the National Conventions.

On April 18 Prof. Binns gave an illustrated lecture on

Pyrometry using a number of excellent slides which had been loaned by Mr. Charles Engelhardt of New York City.

On April 24 Prof. Shaw gave an illustrated lecture on the construction and operation of By-Product Coke Ovens.

REPORT OF UNIVERSITY OF ILLINOIS STUDENT BRANCH

R. K. HARSH, COUNCILOR.

A petition to organize a Student Branch of the American Ceramic Society was presented in accordance with the rules at the Annual Meeting in 1916 by representatives of the Ceramic Club at the University of Illinois. Notification was received shortly after that the petition had been granted and President Barringer suggested that a date be arranged for installation.

Steps were then taken toward re-organization of the Club and application was made to the Council of Administration of the University of Ilinois for permission to form the new Society. As arrangements were not completed until rather late in the semester, it was thought best to postpone installation until Fall.

The time of the Dedication of the new Ceramics Building at the University seemed to be best suited for the ceremonies of installation of the Student Branch and arrangements were made for December 7th, 1916. On that evening a meeting of the Ceramics Club was called to order by the President, C. E. Bates, for the purpose of re-organization and installation of the University of Illinois Student Branch of the American Ceramic Society.

Following the disbanding of the Ceramics Club the meeting was called to order with the following temporary officers: Chairman, C. E. Bates; Vice-Chairman, A. D. Christopher; Secretary, R. M. Chittenden.

President L. E. Barringer was introduced as the representative of the American Ceramic Society and made the principal address of the evening and conferred the charter for the new Student Branch. Past-Presidents of the Ceramic Society, C. F. Binns, A. V. Bleininger, R. C. Purdy and C. W. Parmelee

were present and gave short talks to the new organization. Mr. W. P. Blair, Secretary of the N. P. B. M. A., Mr. J. E. Randall, and Prof. E. W. Washburn also spoke. Greetings to the new Student Branch from the Illinois Sections of the American Institute of Electrical Engineers and the American Society of Mechanical Engineers were expressed by Mr. L. V. James.

The report of a committee on constitution was presented and adopted. Officers of the Student Branch were elected for the remainder of the semester, as follows: Chairman, C. E. Bates; Vice-Chairman, A. D. Christopher; Secretary-Treasurer, R. M. Chittenden.

The charter membership numbered twenty-two. The meeting was then adjourned to the Beta Theta Psi Fraternity House where a smoker was held in honor of President Barringer and the guests of the organization.

At the regular meeting of the Student Branch on January 11, 1917, officers were elected for the second semester: Chairman, J. W. Wright; Vice-Chairman, G. E. Sladek; Secretary-Treasurer, J. L. Crawford. Owing to a conflict in program arrangements the meeting was adjourned to attend a lecture and discussion of "Brick Paved Highways", before the Highway Engineering Short Course which was being held at the University at that time.

At the regular meeting of February 8th, papers were presented by Mr. C. A. Stone on "The History of Enameling", and by Mr. Gordon Klein, on "Modern Methods in Enameling of Sheet Steel".

At the regular meeting of February 22d, papers were read by Mr. R. W. Hummeland on "The Life of Josiah Wedgwood", and by Mr. G. E. Sladek on "The Life of Bernard Palissy". These papers were the first of a series on the "General Subject of Pottery". Later a series of papers will be presented on "The General Subject of Glass."

The present membership of the Student Branch is twenty-five.

REPORT OF IOWA STATE COLLEGE STUDENT BRANCH

HOMER F. STALEY, COUNCILOR.

The installation of the Ames Student Branch of the American Ceramic Society was conducted on January 16th, 1917, at Ames, Iowa. Professor A. V. Bleininger of the Bureau of Standards, as a trustee of the American Ceramic Society, and acting for the president, presented the charter. Mr. Bert Sweely was elected chairman and Mr. Lowell Hewitt, secretary-treasurer of the new Branch. Homer F. Staley had previously been designated as councilor by the Board of Trustees of the Society. The newly elected chairman then thanked Professor Bleininger and the parent society for the honor conferred on the Ames Student Branch. Short addresses were made by W. J. Goodwin, president of the Iowa Clay Products Manufacturers' Association; by C. B. Platt who for many years was secretary of the Iowa Clay Products Manufacturers' Association, and who was largely instrumental in having the ceramic department established at Iowa State College; by H. R. Straight, president of the Permanent Buildings Society of Iowa; and by Homer F. Staley, professor of Ceramic Engineering at Iowa State College.

The installation was conducted during the week of the annual Ceramic Institute and Clay Products Manufacturers' convention at Iowa State College. The members of the Iowa Clay Products Manufacturers' Association and of the Permanent Buildings Society of Iowa attended in a body; over 150 ceramic men being present.

The Branch started with a charter membership of 12 which has since grown to 14. From the time of the installation of the Branch until the closing of school, meetings were held every two weeks. The students have evinced great interest in the work of the Society and they seem to be deriving considerable profit from their association.

IN MEMORIAM

CHARLES WEELANS

Charles Weelans, a former President of our Society, died on December 12th, 1916, after a very brief illness.

He was born on the 17th of June, 1863, in Barnaby, Yorkshire, England. While still an infant, his parents emigrated to this country and settled in Trenton, N. J. At the early age of fifteen he was put to work in a pottery. At twenty-five, he was made superintendent of the Upper Greenwood Pottery. Subsequently, he was connected with the Trenton Potteries Company, and then, about twenty-one years ago, with some friends, he established the Monument Pottery with which he was connected until last January. In July, he undertook the building of one of the largest Sanitary Manufacturing Potteries in the Country at New Brighton, Pa., where his plans and activities were stayed by the hand of death.

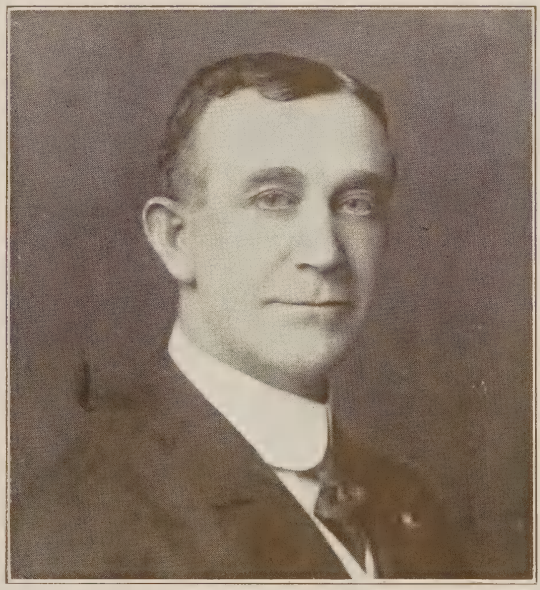
Mr. Weelans was a man of sterling qualities which endeared him to all his friends. He was devoted to the interests of this organization, and was an untiring worker in the interests of ceramic education. Unselfish, warm-hearted, and loyal; we who knew him, loved him, and mourn his untimely passing from our circle.

WALTER A. DENMEAD

Walter A. Denmead died suddenly at Schenectady, N. Y., on April 8th, 1917.

Mr. Denmead was a graduate of the course in Ceramics at the Ohio State University, class of 1910.

In 1912 Mr. Denmead entered the employ of the General Electric Company at Schenectady, N. Y., as a ceramic specialist to work upon the development of various ceramic products used as insulating materials for electrical apparatus. He was actively engaged in many problems connected with the manufacture of electrical porcelain, enameled metal and enameled ware specialties. At the time of his death he had became an important



CHARLES WEELANS
President 1911-12
Died Dec. 12th, 1916

contributor to the development of the General Electric Company's ceramic products and was engaged in research and development work of a high order.

At the last meeting of the American Ceramic Society Mr. Denmead had been elected to full membership and was also made chairman of the newly created Committee on Standards.

In technical and professional standing Mr. Denmead ranked high amongst his associates, while his genial personality won him many friends not only amongst the ceramic profession, but throughout the community in which he resided.

At the time of his death, when only twenty-nine years of age, he had entered upon what promised to be a most successful career.

LEONARD B. COULTER

In the death of Mr. Leonard B. Coulter which occurred on October 26th, 1916, the American Ceramic Society has lost one of its most loyal and faithful members. Mr. Coulter was a man of extremely modest disposition and was at no time inclined to put himself forward. Despite this fact, he possessed a large circle of friends who had learned to appreciate his sterling qualities, his transparent honesty, integrity, and kindliness of heart.

Mr. Coulter was born near Oxford, Ohio, November 24th, 1877, and upon completing the training of the Oxford Public and High School, he entered Miami University from which institution he was graduated in 1898. During his college course he specialized in chemistry and physics. After several years of work in different lines he entered the course in ceramic engineering at the Ohio State University which he completed in 1904. He then entered the employ of Professor Orton as Superintendent of the pyrometric cone factory at Columbus, a place which he held until 1908. At that time he accepted the position of research Ceramic Engineer with the Carborundum Company at Niagara Falls, N. Y., where he remained until his death.

Mr. Coulter contributed several papers to our Transactions as follows:

A Comparative Study of Cornwall Stone and Feldspar in Raw Lead Glazes.

Note on the Fluxing Effect of the Addition of Clay to Cone Mixtures Containing Little or No Clay.

Influence of the Rate of Cooling on the Toughness of Vitrified Paving Brick.

During the summer of 1916 our friend had been ailing and finally his heart became affected, a condition which caused his death on October 26th at Niagara Falls. His body was taken to Fort Worth, Texas, and interred in Greenwood Cemetery. In him his family lost a loving husband and father, his employers a man, valuable in the councils of the organization, and we, his friends, a true hearted comrade. We join with the bereaved family in mourning his loss.

PAPERS AND DISCUSSIONS

(67)

PRESIDENTIAL ADDRESS

LAWRFNCE E. BARRINGER, SCHENECTADY, N. Y.

In conducting the affairs of any organization it is well to occasionally pause and take a survey of what has been accomplished, to review the purposes and activities of the organization and to apply the results of this introspective study to the formulation of plans for the future. In such reviews it is nearly always found that certain lines have become unintentionally overextended, other phases of the work have been somewhat neglected or have not kept pace with changing conditions and that in nearly all branches of the work a better idea can be had of the best means of carrying along the work in the future. Certain activities will be found in such condition as needs no further stimulation but will automatically progress as planned whereas others will require more attention, either because of lack of organized effort behind them or of having been brought into a position of greater relative importance, by industrial or other changes, than was originally anticipated. In a commercial enterprise the annual report serves this double purpose of ascertaining the net results of accomplishment during a year just closed and of providing a basis upon which to carry on the work during a period just commencing.

It is in this spirit of using the experience of the past and present to obtain a clearer perspective of the immediate future that I wish to bring to your consideration a few matters to which I have given thought since our last annual convention at Cleveland a year ago.

The American Ceramic Society was originated and held its first meeting in February, 1899, at Columbus, Ohio, since when its affairs have been wisely and conservatively managed and conducted in accordance with the commendable principles of its founders. Much indeed has been accomplished and the field of technical ceramic knowledge has been lifted from an obscure and chaotic condition and placed upon an orderly and organized

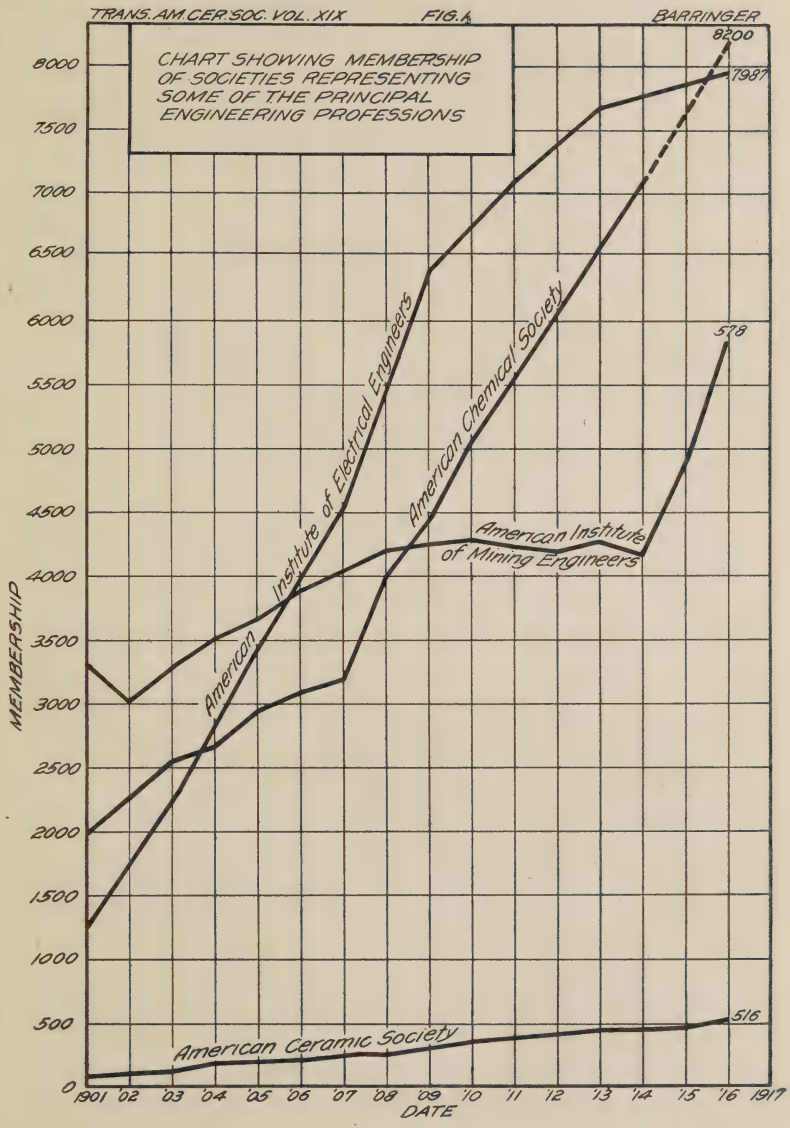
basis.[1] The Society has put its hands firmly upon the plough of progress and driven it deep through the hard crust of tradition and inertia. Technical ceramic education and ceramic knowledge have been advanced to a conspicuously great degree. Industrial progress has been stimulated and the quality of American ceramic products brought higher. Professional standing of the membership has been advanced and professional ethics of a high order encouraged. This has been done not only through the personal association of the membership at the Society's conventions, but also through the publication of papers and addresses relating to the ceramic industry, as in other technical societies, and it is to be noted with gratification that the range of such literature has constantly widened and the quality progressively improved.

In a Society founded and now well established upon such a basis, it seems to me that justification exists for extension of activities, particularly in view of the importance of the industry which the Society represents.

MEMBERSHIP

Examining our records of membership, it is apparent that we have had no mushroom growth and it is undoubtedly to the Society's interest that greater emphasis has been and should be placed upon the character of the membership than upon its mere mechanical size. Upon the other hand, membership should be considered with reference to the importance of the industry, extent of technical ceramic education and the relative growth of similar societies representing proportionately equal fields of industrial work. The adjoining table and curves show the relative growth of the membership of the American Chemical Society, American Institute of Mining Engineers, American Institute of Electrical Engineers and the American Ceramic Society since 1900. It will be observed that our *rate* of growth is comparatively slow, but the question may be asked as to whether the extent of the ceramic industry is such as to warrant expectation of a more rapid rate of growth as compared to other societies.

[1] Past achievements were ably described in the presidential address of Mr. Chas. Weelans, published in Volume XIV of the transactions.


TRANS. AM. CER. SOC. VOL. XIX
FIG. 1.
BARRINGER
CHART SHOWING MEMBERSHIP OF SOCIETIES REPRESENTING SOME OF THE PRINCIPAL ENGINEERING PROFESSIONS
8200
7987
578
516
American Institute of Electrical Engineers
American Chemical Society
American Institute of Mining Engineers
American Ceramic Society
MEMBERSHIP
DATE
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
1901 '02 '03 '04 '05 '06 '07 '08 '09 '10 '11 '12 '13 '14 '15 '16 1917

The tabulation in table II shows comparative statistics in 1909 and 1914 for the chemical, electrical and ceramic industries and partly for the mining industry. This will serve to indicate that the ceramic industry is no mean rival of the other great industries in extent and value. The membership of the American Ceramic Society should reach a large part of the industrial field and the benefits of increased membership in the industry will be mutually advantageous.

The ceramic industry is among if not the oldest in the world and has always been of great economic importance. I need not mention here the many products of clay, glass and cement which enter into the necessities and comforts of all mankind.

With such an industry there is increasing need of technical knowledge. The American Ceramic Society stands for the acquirement and dissemination of such knowledge and therefore a greater membership will prove highly desirable to both the industry and the Society.

It is my recommendation that this Society, therefore, create a standing committee on membership to advance the growth of the Society more consistently with the industrial growth just indicated and with the increase of ceramic technical education which will be mentioned later. We are entitled to at least one thousand members immediately and an organized campaign should be put under way to secure this increase.

A very much larger membership is one of the fundamental conditions necessary for expansion in other directions as has been proposed from time to time. Certain of our members have, for instance, requested publication of a monthly journal. This undertaking would involve considerable expense and greater revenue can come only from greater membership or increased dues.

EXTENSION OF INFORMATION WITH REFERENCE TO CERAMICS AND THE AMERICAN CERAMIC SOCIETY

The generally accepted meaning of ceramics amongst present day ceramists is that field of activity dealing with the use and production of silicates. In some branches of the industry silicates are produced from materials other than silicates, as in the

TABLE II. COMPARATIVE STATISTICS.

	CHEMICAL INDUSTRIES.* (Consolidated.)		ELECTRICAL MACHINERY.†		MINING INDUSTRY.		CERAMIC INDUSTRY. (Clay, glass and cement.)	
	1909.	1914.	1909.	1914.	1909.	1914.	1909.	1914.
Number of Establishments ..	2,140	2,461	1,009	1,030	92,000	.....	5,535	4,115
Persons Engaged	88,097	111,458	105,600	144,712	.....	.....	228,382	229,862
Value of Products	$425,084,540	$547,801,937	$221,309,000	$335,170,000	$1,869,425,838	.....	$324,195,000	$398,699,000

* Embraces chemicals, explosives, sulphuric nitric and mixed acids, wood distillation, paints and varnishes, fertilizers, dyestuffs and extracts, essential oils and bone, carbon and lampblack.

† Machinery, apparatus and supplies.

glass and metal divisions, whereas in other branches both the raw materials and the finished product are most largely silicates as in the clay and cement branches. There are exceptions of course, as in producing magnesite brick or certain cements, but even in these the same general processes of ceramic manufacture are followed, as forming, drying, burning, grinding, etc. The great bulk of ceramic products, however, are silicate products and there is probably no branch of industrial work which can be more sharply or consistently classified and defined.

The term ceramics is still somewhat loosely or indefinitely applied by those not immediately interested in ceramic work. In Chemical Abstracts, published by the American Chemical Society, section 19, is entitled "Glass and Ceramics" and section 20 "Cement and other Building Materials". In the first instance the terms glass and ceramics are co-ordinated instead of the first being subordinated to the general term and in the second instance cement is classified with other than ceramic products. I have brought this matter to the attention of the editor of Chemical Abstracts and am pleased to report that there is a disposition to discuss this matter with representatives of our Society and to make such adjustments as will be mutually satisfactory.

In the collection and publication of Government statistics the clay, glass and cement statistics are handled in different departments and published in different departmental bulletins. The Geological Survey collects statistics covering the clay and cement industries and the Bureau of the Census those covering the glass industry. I have taken up with the officials of these departments the advisability of handling these statistics as a unit under the designation "The Ceramic Industry, clay, glass and cement," and while there are certain stated disadvantages in such an arrangement, I find that the matter will receive consideration and that suggestions from this Society would be given careful attention.

I mention these cases as illustrating the need of active presentation of the matter if the term ceramics is to become more generally accepted as understood by this Society and if the various branches are to become more closely related in public

and general professional opinion than at present seems to be the case.

Then there is the matter of literature. During the past year or so during which electrical engineers have been active in the investigation of the causes of failure in porcelain insulators for high tension transmission lines, surprise has been expressed amongst them of the amount of investigational work in porcelain already carried out by the American Ceramic Society. Why our proceedings were not more generally known it might be difficult to explain and equally difficult to find a satisfactory means of adjustment.

With such a question as firmer establishment of the term ceramics, however, I would again recommend a standing committee as the best means of procedure. Perhaps such a committee would be that of a Committee of Standards and this committee would find many other related subjects to engage attention.

In connection with the work of the Committee of Standards I would suggest revision and re-issue of the Manual of Ceramic Calculations which might be broadened and made of much wider general interest. In addition to tables and information of interest to ceramic chemists or engineers it might be advisable to collect and tabulate the Society's definitions, as formulated from time to time, as Orton's "Vitrification", Burt's "Faience", etc., together with accepted classifications of clays, ceramic wares, etc. I should like to see a ceramic handbook built up on the basis of and replacing the old manual of ceramic calculations and such a book constructed and revised from time to time by a standing committee of standards which would also handle such questions as securing proper use of ceramic terms.

This is a mere outline of a suggestion but I am convinced that a Standards Committee would find much work of importance. There would be standardization of terms and of methods of test. A number of our members have expressed a desire to have standard methods of testing clays and other ceramic materials worked out and adopted.

CERAMIC EDUCATION

There is a vital connection between technical ceramic education and the American Ceramic Society.

In 1894 the first course in ceramics in this country was offered by the Ohio State University with Professor Edward Orton, Jr. as the originator and first instructor. At first a two-year short course was established and in 1896 a four year or full engineering course. This work has grown steadily and today there is a splendidly equipped department with from 70 to 80 students enrolled.

In 1900 the New York State School of Clay-Working and Ceramics was founded at Alfred University, Alfred, N. Y.[2] and has grown into a strong department of some 30 or 40 students. An engineering course is offered and also special attention given to art pottery or decorative ceramics.

The ceramic course at the University of Illinois was instituted in 1905 and has grown into a splendid department of some 50 or 60 students. Last December there was dedicated a building devoted entirely to the work of ceramics and the mechanical equipment thus made available is probably the most modern and complete which now exists. A full engineering course is offered and also advanced and special courses.

A department of ceramics was established at Rutgers College in 1902 with a four year engineering course only. The number of students has not been as large as in the departments previously mentioned and probably averages less than 15, although the college is located in one of the leading clay-working states of the country.

The University of Iowa established a course in ceramics in 1903-04, and the department is in good condition with from 30 to 40 students.

A department of ceramics was established in the Oregon School of Mines[3] in 1914 with a full engineering course, the number of students not yet being known as the technical course is not specified until the Junior year.

---

[2] See "Recent Developments and Improvements at the N. Y. State School of Clay-Working and Ceramics," E. T. Montgomery. *Trans. Amer. Cer. Soc., Vol. XVI*, Pg. 371.

[3] See "A Department of Ceramics in the Oregon School of Mines," Ira A. Williams. *Trans. Amer. Cer. Soc., Vol. XVI*, Pg. 244.

In addition to these six established ceramic departments there have been special courses offered in other educational institutions as in the Geological Department at Cornell University and in the Central Technical School of Toronto.

This brief survey will indicate the growth and extent of ceramic education and the number of young men now being trained for and yearly entering the ceramic industry and the ceramic profession.

It is of importance that this Society establish an early relation with these recruits to the profession and equally, if not more, important that the newly trained men associate themselves with the Society.

Technical education may be defined as the special training which *helps* to qualify a person to engage in some branch of productive industry.[4] In this definition it should be noted that technical education is the special training which *helps* to qualify persons for some particular industrial work and it is inferred that such specal training does not usually completely prepare one for successful participation in a given field. There must be training supplementary to the technical education or special training. Men have risen to the rank of captains of industry both with and without the assistance of technical education and I have personally known two presidents of great corporations of whom one in youth received the technical training of an electrical engineer, whereas the other had mastered for himself the technicalities of mechanical engineering particularly as applied to the building of steam locomotives.

So-called technical education is usually received at technical schools or colleges and consists in studying the science or sciences to eventually engage. Inasmuch as this education or preparation serves simply as a *help* or *partial preparation,* the question naturally arises as to what forms *the other requirements* essential to success or progress to a satisfactory degree or to the fullest extent possible with given natural ability and certain degrees of opportunity.

The requirements for complete qualification other than technical education, might be given as practical experience, good

[4] *Encyclopedia Brittanica.*

judgment and clear thinking in applying scientific or technical knowledge, an apprecation of the work done by others in the same line and enthusiasm or personal belief in the value of the work to mankind apart from its commercial standing. These supplementary requirements do not necessarily include such personal elements as initiative, energy, executive ability and determination.

Amongst the available means for acquiring training supplemental to technical education, it is well known that actual experience gives the student knowledge of practical conditions as well as an opportunity to study the application of scientific principles to the advancement of some particular line of work. This also affords an opportunity of observing the practical value of the work of others and frequently stimulates thought and effort or creates additional enthusiasm for the art.

As a second available means of supplemental training I wish to suggest technical societies. A technical society may be defined as a group of persons organized upon the basis of common interest in some particular line of work to promote the advancement of both the work itself and of the individuals engaged therein.

Although stated in different ways, the purposes of this and other Technical Societies are fundamentally the same, that is, (1) to advance the science. (2) to improve the industry, and (3) to dignify and uplift the profession. In all societies this is to be done primarily by meetings for the reading and discussion of formal papers and by the subsequent printing and circulation of such papers and discussions.

To stimulate interest, quicken the perception and broaden the professional standing of the younger ceramic engineers it is essential that early association be formed with the American Ceramic Society. The regular acquisition of such younger members with fresh ambitions, new thoughts, and desires for high professional standing will of course react to form a greater ultimate strength of our society.

This society will do well to give special attention to the graduates of these ceramic courses. This is being done in a measure by the recent institution of Student Branches but may

be furthered by still closer connection. Here again I would recommend a committee, this time an Educational Committee, such as that of the American Institute of Electrical Engineers. This committee would not only follow student work but might advantageously co-operate with educational department heads, of whom some would no doubt form a part of the committee, to bring about a close and active relation between the best engineering practice as revealed by the Society's proceedings and the work offered to students by the various colleges.

Such a committee of the Society might often be of value in aiding ceramic education where it does not seem to be properly endorsed or supported by the state or college officials, particularly in the matter of appropriations, or where ceramic departments are not receiving proper support from the ceramic profession in the immediate state.

In the matter of creating a closer relation between engineering practice and under-graduate studies, I have particularly in mind the subject of drying, which I am under the impression does not receive the attention it deserves in under-graduate instruction. This is one of the most important features of ceramic manufacture particularly in high-grade clay wares and there is much opportunity in this field for the application of strictly scientific principles, which will lead to very marked reductions in time of production, economy of handling and a very much smaller loss of ware.

I should also like to see undergraduates stimulated to take a greater interest in the production of ceramic apparatus, as kilns, driers, machinery, etc. There are very few technical ceramic men in this line.

An educational committee would keep the Society informed from year to year as to progress in all ceramic educational departments and in following the work of the undergraduates would co-operate with the membership committee from time to time with a view to having a large proportion of these men become members of the American Ceramic Society to the general advantage of the entire field of ceramic activities.

LOCAL SECTIONS AND STUDENT BRANCHES

In connection with this matter it may be said that the work of the Society is progressing upon quite a satisfactory basis.

Local sections and student branches should be established only where there is a sufficiently strong center of ceramic interest to maintain such sections and student branches in a strong, healthy condition. Such a subordinate division of the parent Society would become burdensome if established upon an insecure basis or where the conditions are such as to make doubtful continuation of the local chapter in a very active state.

At the beginning of my term of office there was one local section and two student branches, namely, the Beaver Section of the American Ceramic Society, founded August 26, 1915, the Ohio State University Student Branch, established May 1915, and the New York State Student Branch, established in October 1915.

The year has witnessed the installation of two other student branches, namely, the Illinois Student Branch, created and installed in December 1916 and the Iowa Student Branch, established in January 1917.

The Society thus has four student branches and one section all of which are in excellent condition as far as is known at this writing.

It might be advisable, although I do not strongly urge the matter, that a committee be created on local sections and student branches to follow the work of these bodies enough to keep firmly cemented their bond with the American Ceramic Society and to stimulate local technical papers and discussions and the presentation of selected contributions to the parent Society.

PROFESSIONAL PAPERS AND DISCUSSIONS

The American Ceramic Society was founded by those primarily interested in the production of clay wares and as a consequence a greater emphasis was given this branch of the ceramic industry than to the other factors of cement and glass, or to the smaller but important branch of metal enamels. During the past few years there has been evidence of a better balance in the

papers and discussions devoted to clay wares and those in relation to the other ceramic arts, but it is my belief that there is room for improvement in this direction. This will largely be brought about by the increased membership which I recommend, for in this enlarged membership, we should include a number of technical men engaged in the glass and cement fields who have not yet been brought into contact with our Society.

CERAMIC PRODUCTS OF NATIONAL IMPORTANCE

During the past year it has been suggested by one of our members (Mr. Bleininger) that our Society should take the initiative in developing ceramic products which are of national importance from the viewpoint of increased competition at the close of the present European war. I have discussed this matter with several of our members and am heartily in sympathy not only with the Society undertaking to stimulate American production of ceramic products to successfully compete with European wares as a commercial proposition but am also very much in favor of this Society taking the initiative in developing ceramic products whch are of national importance in time of war. There are ceramic products which are of increased importance in times of war and yet which are not produced to the best advantage in this country. I have in mind particularly optical glass and certain lines of porcelain. Optical glass is particularly important in the matter of making range finders, periscopes and field glasses, all of which are of considerable importance in times of war.

This matter is one in which the American Ceramic Society has the opportunity of taking the initiatve before the other technical societies, whose lead we must necessarily follow in a great many other ways, which I have indicated.

It seems to me we should create a committee to be called "Committee on Ceramic Products of Importance to National Preparations," or by some other appropriate designation and that this committee should seek to stimulate the production of (1) those ceramic products for which our country has special need in times of war and (2) those ceramic products subject to the closest competition in quality and price by the products of foreign nations.

CONCLUSION

In closing I would say that our progress in the past has been excellent but has been judged largely by our opinions of one another and of the things we have accomplished for our mutual benefit. For the future I propose broader activities and increased efforts to secure a more important and more widely recognized place in the world's work, and our success in this direction will be measured not so much by our own opinion as by what others think of us, as a society and as individuals. I regret that this message falls at the close rather than at the beginning of my term of office, but I assure you of my desire to serve in any way deemed best after relinquishing the high office with which you have honored me. There is no organization in which I have a greater interest nor for which I have a greater ambition than for the American Ceramic Society, and I am ready to assist in carrying out any of the proposed lines which may appeal to you.

Finally, I desire to express my appreciation of the co-operation extended by the officers and members during the year in which I have been your president and, for whatever work we undertake, I can assure you that at least we do not lack the spirit of co-operation or of unselfish and cheerful devotion to the cause of ceramics upon the part of our present membership.

VOLUME CHANGES OF SOME COMMERCIAL SILICA BRICKS ON HEATING[1]

BY DONALD W. ROSS, PITTSBURGH, PA.

Crowns and side walls of open-hearth steel furnaces, other metallurgical furnaces and by-product coke ovens consist largely of silica brick. Such uses are very exacting, and not all makes have proven entirely satisfactory. Up to the present time not a great deal of work has been done to prove what the desirable qualities are, what factors control them and what tests should be applied. In attacking this subject three phenomena are here considered — permanent change in volume caused by a given heat treatment, the incident variation of pososity, and specific gravity.

Practically all silica brick now manufactured in the United States contain at least 96 percent SiO_2. Ordinarily the balance is chiefly lime (CaO), alumina and iron, usually in the order named. The brick are manufactured by crushing quartzite so that the coarsest particles are approximately ¼ in. diameter, and adding 2 percent of CaO, as milk of lime, and enough water so that the material can be hand molded in steel molds. When dry the bricks are slowly burned to approximately cone 18. The lime serves as a binder in the dried state and, in burning, fluxes the silica slightly, thus bonding the brick firmly together.

Silica brick are particularly useful in industrial work due to their rigidity at temperatures beyond the usefulness of ordinary fire clay brick, and because of the absence of shrinkage and because they expand slightly when heated.

Being composed almost entirely of SiO_2, silica bricks act primarily as does silica. The stability relations of the different crystal modification of SiO_2, as determined by the Geophysical Laboratory of the Carnegie Institution, briefly summarized are:

[1] By permission of the Director, Bureau of Standards.

Inversion	*Temperature*	*Remarks*
α quartz — β quartz	575° C.	Rapid, reversible.
β quarts — β_2 tridymite	870° ± 10°	Very sluggish, reversible.
β_2 tridymite — β cristobalite	1470° ± 10°	Very sluggish, reversible.
α tridymite — β_1 tridymite	117°	Rapid, reversible.
β_1 tridymite — β_2 tridymite	163°	Rapid, reversible.
α cristobalite — β cristobalite[2]	220°-275°	Rapid, reversible.

The alpha-beta cristobalite inversion, which occurs between 220° C. and 300° C. is accompanied by a volume charge of approximately 3.0 percent. The alpha-beta quartz inversion at 575° C. is also accompanied by a volume change of approximately 1.4 percent. These two volume changes, particularly the one at the lower temperature, tend to cause silica brick to crack and spall when cold brick are heated rapidly and again when cooled. This is largely overcome by more gradual heating, and cooling. The alteration of quartz into one of the other crystal forms, of course, obviates the strains from this cause, and as tridymite does not exhibit any large sudden volume change, any material that alters to tridymite also tends to lessen the tendency of the brick to crack on heating.

If silica brick has only been burned to a slight degree, a large proportion of the material remains as unaltered quartz. Such brick when built into an industrial furnace and heated, will develop undue permanent expansion, which tends to weaken the structure of the brick and may in extreme cases disrupt certain furnace parts. If, on the other hand, a brick has been slowly burned to an advanced degree, much of the material will have inverted into cristobalite and tridmite, so that additional heatings will not develop much more permanent expansion. The slow burning allows the brick to become thoroughly bonded so that it can later withstand the shocks of sudden heating and cooling. Hence, if we determine permanent expansion produced on reheating of silica brick we have a measure of the degree to which they have been burned. Tests of this nature on 14 varieties of commercial brick are presented. One to four inclusive, Table I, are of Pennsylvania

[2] Temperature depends on previous heat treatment. Probably monotropic, changes slowly to chalcedony, tridymite or quartz in the presence of a flux at relatively low temperatures.

quartzite of the Tuscarora, or, as it is more familiarly known, Medina formation. Five to seven inclusive are of Wisconsin Pre-cambrian quartzite of the Baraboo or Devil's Lake deposit. The balance are representative brick made from other quartzites. The chief silica brick districts of the United States are included.

The heatings were made to three different temperatures, and different specimens were used for each heating. For each heating from two to four specimens of each variety were used. These consisted of cubes, approximately 2 inches on a side, cut from brick which had received the usual burn at the various places of manufacture. These pieces were thoroughly dried at 110° C., after which their volume and porsities were determined by weighing dry, saturating with water and weighing wet, then weighing the saturated piece suspended in water. From these figures we find the volume by subtracting the suspended weight from the wet weight, and the volume of the pore space by subtracting the dry weight from the wet weight, or,

$$Volume = Wet\ weight - Suspended\ weight,$$

$$Porosity = \frac{Wet\ weight - dry\ weight}{Wet\ weight - suspended\ weight}$$

The saturation was obtained by placing the pieces in an iron cylinder, covering them with boiling water and subjecting them to a vacuum equivalent to 24 inches of mercury, for four hours. The pieces were again thoroughly dried at 110° C., and the volumes checked by means of the Seger volumeter, using kerosene as the displacing liquid. Each piece was measured twice, and the mean taken. Three or more readings were taken unless the first two agreed to within 0.2 cc. for a 150 cc. piece. These weighings and the volumetric work were repeated with the pieces after they had been subjected to the given heat treatment. From this data have been computed the volume expansion of the pieces (in percent) caused by these burnings, the percent porosity, both before and after, and the specific gravity. These volume measurements represent the exterior volume of the piece in each case, and the percent volume expansion is based on the original volumes of the pieces.

After evaporating the oil from the test pieces at 110°C. they were fired in a gas-fired down-draft test kiln, which had a silica brick floor with the brick laid on the flat. A small silica brick piece at the center of the kiln supported the end of a platinum-platinum rhodium thermo-couple and a plaque holding Orton-Seger pyrometric cones. The test pieces were grouped about this. The different pieces of any one variety were placed on opposite sides to insure average heat treatment for all varieties. The heating was as follows: — The temperature was uniformly raised to 800° C. in 18 hours, then along a smooth curve, which flattened out toward the end, the desired temperature was reached in 6 hours. This temperature was held for 1½ hours, and the kiln shut off. The test pieces were cold after 24 hours. Such treatment brought cone 15 down for the 1400° C. burn, come 17+ for the 1450° C. burn, and cone 20+ for the 1500° C. burn.

In Table I under each temperature the first column represents the porosity of the pieces before being reheated. The second column is the specific gravity before heating, the third is porosity after heating, the fourth is the percentage perma-

TABLE I

1400°C					
NO.	BEFORE		AFTER		
	POR.	SP. G.	POR.	V. EXP.	SP. G.
1	26.46	2.292	26.39	0.64	2.283
2	27.19	2.387	27.60	2.55	2.360
3	31.96	2.342	32.17	1.31	2.323
4	29.56	2.295	29.45	0.42	2.287
5	24.44	2.369	24.93	2.18	2.334
6	25.27	2.434	25.30	2.40	2.387
7	25.37	2.401	25.39	1.62	2.373
8	31.46	2.316	31.63	0.65	2.305
9	22.67	2.496	23.82	6.38	2.389
10	22.67	2.493	23.55	5.62	2.394
11	23.16	2.545	24.68	7.73	2.417
12	30.11	2.316	30.21	0.80	2.309
13	30.64	2.500	31.86	5.22	2.418
14	24.66	2.400	24.66	1.95	2.361
Ave.	26.83	2.399	27.26	2.819	2.352

1450°C

1	26.30	2.304	25.53	0.62	2.270
2	27.07	2.412	27.00	3.24	2.333
3	31.67	2.342	31.70	1.01	2.320
4	29.35	2.301	29.45	0.70	2.291
5	23.72	2.393	24.01	1.14	2.378
6	25.00	2.438	25.02	2.20	2.387
7	24.70	2.400	24.77	2.08	2.354
8	31.77	2.338	31.65	0.12	2.326
9	23.77	2.498	24.88	6.61	2.378
10	22.65	2.499	23.42	5.40	2.390
11	23.08	2.537	24.57	7.15	2.415
12	29.39	2.319	28.87	0.37	2.295
13	30.52	2.497	31.80	5.80	2.404
14	24.68	2.402	25.16	2.31	2.366
Ave.	26.69	2.405	26.988	2.768	2.350

1500°C

1	26.31	2.277	27.96	2.06	2.280
2	27.21	2.381	33.67	13.05	2.308
3	30.94	2.323	32.78	3.12	2.310
4	30.77	2.278	28.60	—0.13	2.281
5	23.57	2.380	25.67	4.34	2.344
6	25.17	2.417	29.50	11.10	2.334
7	24.29	2.385	28.88	8.88	2.330
8	31.11	2.322	32.06	0.73	2.334
9	23.23	2.490	30.17	17.19	2.333
10	22.67	2.475	31.20	19.70	2.322
11	22.64	2.528	31.41	22.10	2.335
12	29.76	2.298	30.45	0.37	2.306
13	30.59	2.491	38.58	20.91	2.324
14	24.56	2.378	31.55	13.05	2.353
Ave.	26.63	2.387	30.89	9.748	2.321

Average of all porosity determinations on original brick = 26.717.

nent volume increase which has resulted from the heat treatment, and the fifth is the specific gravity after the treatment.

Although no proof is here presented, it was found that the amount of skin surface, or surface of the original brick left on the test specimens, does not appear to materially affect the results in the case of silica brick. For the porosity, specific gravity, and volume (by weight) determinations, the accuracy is somewhat impaired when the volume of the piece is less than 150 cc. With moderately open material, such as the average silica brick, a considerably larger piece than this may

be used without much danger of error from retaining air in the center of the piece. In fact, it might be accurate enough for commercial work to use a whole brick.

Considering the data as a whole (Table I) we find the averages indicating that the heat treatments, in general, cause the porosity to increase. Considering individual results, it is seen that usually, the greater the volume change, the greater the porosity increase. Number 10, which is known to have received a light heat treatment in manufacture, shows this clearly. The extreme limits of porosity shown by the original brick indicate what variation may be expected in practice.

In general, increase in pore space is caused by increase in the volume of the solid material, the voids increasing as the volume of the solid material increases. Another slight increase in porosity is frequently and perhaps always caused by a tendency of the material to crack, due to rapid heating or cooling, etc. Increases due to this cause are usually negligible. Acting in opposition to these phenomena is the tendency of the particles to flux and draw closer together, thus tending to neutralize any increase of pore space. This effect is of minor importance and is only apparent in certain cases of well burned brick. It is shown by No. 1 at the 1400° C. and 1450° C. temperatures. The increase in pore space is roughly proportional to the increase in volume of the solid material, except as the above side effects tend to alter that ratio.

The burnings here shown indicate that, for these temperatures, the percentage outside volume increase is greater with brick which have been lightly burned than with those which have received extensive heat treatment, and that with bricks which have approximately reached equilibrium we may even have a volume contraction at 1500° C.

The very great increase in volume at 1500° C. shown by light burned material, as compared with the increases at the lower temperatures indicates that at these temperatures the material had not yet reached equilibrium at the end of the heating.

From the above facts it seems possible to compare the degree of burning of different silica brick by comparing the

volume increase in percent caused by such a single heating to any of these three temperatures. To determine the true degree of burning of materials it is advisable, however, to give them repeated burnings to any one temperature, until approximate equilibrium is reached, that is until additional heating causes no further increase in volume. Comparing these volumes will indicate how near equilibrium the original pieces were.

Varieties Nos. 1, 4, 8, and 12 show only a small volume increase at any of the temperatures and at 1500° C. variety No. 4 shows a decrease in volume. Likewise there is very little change in porosity of these varieties at any of the temperatures. From these facts we may assume that these materials have in the course of manufacturing approximately reached equilibrium for the temperatures under consideration. In support of this idea, it is known that these bricks did receive considerably more heat treatment than is usual with many of the other varieties.

Commercial burnings of silica brick seldom exceed a temperature of 1450° C. The volume decrease of No. 4 at 1500° C. indicates that in cases where equilibrium has been approximately reached for a temperature of 1450° C. we may look for a slight volume decrease when heated as above 1500° C. From the nature of the crystalline forms of silica, it is safe to assume that this is due to an increase in density of the silica itself. This increase in density may be obscured in some cases by a light increase in porosity, the volume increase due to increased porosity being more than the decrease caused by increased density.

Averages of the Pennsylvania group, Nos. 1-4 inclusive, show the results compiled in Table II. These figures may be fairly indicative of what is to be expected from the average Pennsylvania brick made from Tuscarora quartzite. A point of interest in this connection is the wide variation in porosity of brick made from very similar materials.

The averages of the Wisconsin group, Nos. 5-7 show the results given in Table III. The average porosity of this group is somewhat lower than is the case with the Pennsylvania group,

TABLE II

BEFORE		1400°C			1450°C			1500°C		
		BEFORE	AFTER		BEFORE	AFTER		BEFORE	AFTER	
EXTREMES OF POROSITY	AVE. POROSITY	POR.	POR.	V. EXP.	POR.	POR.	V. EXP.	POR.	POR.	V. EXP.
26.3-31.96	28.72	28.79	28.90	1.23	28.57	28.42	1.39	28.81	30.75	4.52

TABLE III

BEFORE		1400°C			1450°C			1500°C		
		BEFORE	AFTER		BEFORE	AFTER		BEFORE	AFTER	
EXTREMES OF POROSITY	AVE. POROSITY	POR.	POR.	V. EXP.	POR.	POR.	V. EXP.	POR.	POR.	V. EXP.
23.57-25.37	24.61	25.03	25.21	2.066	24.47	24.60	1.81	24.34	28.02	8.11

and the variation in porosity is considerably less. Otherwise the two groups are quite similar. The number of members of these two groups is so limited, however, that they are merely presented, no attempt being made to draw general conclusions.

If we omit varieties Nos. 9, 10, 11, and 13, which are materials intended for a special purpose that have received rather light burning, the average volume expansions of the remainder; viz., 1.45 percent at 1400° C., 1.38 percent at 1450° C., and 5.66 percent at 1500° C., will indicate what may be expected from average brick, in one heating as above. Built into a furnace where the brick will eventually reach equilibrium, the final expansion would, of course, be somewhat more than these figures indicate.

The specific gravity of raw quartzite or crystalline quartz and flint, according to J. W. Mellor[3] ranges from 2.59-2.66. The figures of Table IV represent specific gravities of 12 pieces of raw American quartzites. Two of these varieties are nearly non-porous, and the third is an open porous variety. All three varieties are used to some extent for making silica brick. These specific gravities were computed from the wet, dry, and suspended weight measurement made as described above. This was done by dividing the dry weight of the piece by the volume

TABLE IV. SPECIFIC GRAVITIES OF RAW QUARTZITES

Close grained	2.650	2.650
	2.650	2.650
	2.650 Mean	2.650 Mean
Open porous material	2.620	2.604
	2.610	2.600
	2.615 Mean	2.602 Mean
Close grained	2.646	2.642
	2.638	2.638
	2.642 Mean	2.640 Mean

[3] *Trans. English Ceramic Society, Vol. 15,* Part 1, p. 77.

of the solid material, *i. e.*, exterior volume minus the pore volume, or

$$Specific\ gravity = \frac{dry\ wt.}{(wet\ wt. - sus.\ wt.) - (wet\ wt. - dry\ wt.)}$$

Each group of two determinations for a variety were made on the same day, but the different groups of determinations were made on different days. The degree of agreement of the determinations for any one variety can be seen from the figures. Corrections for temperatures, of course, are necessary.

The Geophysical Laboratory and others have indicated that the specific gravities of artificial tridymite and cristobalite are approximately 2.270 and 2.333 respectively. The specific gravities shown in Table I for brick are all within the limits of raw quartzite and tridymite; viz., 2.660—2.270. The specific gravity difference from 2.66 — 2.270 is so great, that even if this method of determining specific gravities were not very accurate, it would still be accurate enough to designate clearly the degree to which a silica brick has been burned. In fact, it now appears that this is by far the most accurate, as well as the easiest method of determining the degree to which brick has been burned. To approximately determine the degree of burning, it is only necessary to find the specific gravity, in this way, on a piece of the brick as it comes from the manufacturer. This method might readily be used for inspection work at plants where quick results are needed. Omitting Nos. 9, 10, 11, and 13, the average specific gravity of the remainder as they came from the factory is 2.3546.

For more extended work in determining the degree of burning determinations of the specific gravity, after each of several reheatings at one of the above temperatures, should be made. The changes in specific gravity occasioned by these successive heatings will indicate the rate at which any given material approaches equilibrium for the temperature used.

This method of determining the degree of burning has the advantage over the "outside volume increase" method in that it deals only with the solid material and hence is independent

of any porosity changes. The specific gravity data bears out what has been said concerning the volumes and the porosities.

In conclusion, we may say that underburned brick increase both in porosity and outside volume when reheated to 1400° C., 1450° C. or 1500° C. as above, and that the increase in porosity is roughly proportional to the increase in volume of the solid material. With material that has approximately reached equilibrium at 1450° C. we find very little change on reheating at these temperatures, and at times may even obtain a decrease in outside volume for the heating at 1500° C., due to increase in density of the solid material.

By comparing the percentage volume increase of materials which have been once reheated, we can roughly gauge which has been given the most strenuous heating in manufacture; and by comparing the results of repeated heatings at one temperature, we can approximately ascertain how far each original piece was from equilibrium at that temperature. In other words, we have thus a means of testing the quality of silica refractories.

The extreme porosities 22.64 percent and 31.96 percent of the original brick show the range that is likely to be found in industrial practice. The figures 1.45 percent at 1400° C., 1.38 percent at 1450° C., and 5.66 percent at 1500° C. indicate what volume expansion may be expected from average commercial brick when once reheated as above. It is to be expected that when built into a furnace where they will eventually reach equilibrium, the final volume increase will be somewhat more than these figures indicate.

A combination of the volume and specific gravity methods should afford means of determining accurately whether or not silica refractories have been fired to the proper temperature, and thus of fixing the quality of the material. The importance of having available such simple tests of these refractories is self evident, especially for the exacting demands of the by-product coke oven industry.

STUDY OF EFFECT OF VARIATION OF PRESSURE IN THE FORMING OF DUST PRESSED TILES

BY FORREST K. PENCE.

One of the most important stages in the process of manufacture of dust pressed tiles is that of the pressing. The defects here arising are usually due to unequal distribution of the pressure or to insufficient pressure and rarely to excessive pressure. The cause of the defect in such cases is usually apparent from an observation of the relation between the porosity and the shrinkage of the tile in question. High porosity and excessive shrinkage indicate insufficient pressure. Also the tile or portion of tile thus "soft" pressed may develop cracking and warping.

In the case of excessive pressure, an absorptive tile will show abnormally low porosity and low shrinkage. If the tile body belong to the non-absorptive class, excessive pressure may cause it to develop blistering and swelling similar to effect of overfire.

Prof. Parmelee has obtained pressure-porosity curves for two New Jersey fire clays.[1] Pressure was applied in a manner different from that used in pressing of tiles where usually three or more applications and releases are given in order to afford opportunity for air to escape from the clay mass.

The purpose of this investigation is to determine

(1) Relation between pressure and density as obtained in typical tile bodies under normal conditions of manufacture.

(2) Relation between pressure and shrinkage, under the above conditions.

(3) In case of glazed tiles, to determine relation between pressure and glaze fit.

(4) From study of (1), (2) and (3) to determine practical limits of pressure and approximate pressure to be recommended as a practical mean.

[1] *Trans. Amer. Cer. Soc. XVII,* P. 458.

Three typical bodies were chosen, *viz.*, porous body for bright white-glazed wall tile, semi-vitreous or red floor-tile body, vitreous or white floor-tile body. Bodies were selected from clay storage stock and contained 9½, 7½ and 10 percent. of water respectively.

Various pressures were obtained by using a die made to contain thirty-six small hexagon tiles. By using a definite hydraulic pressure upon the plunger head and varying the number of tiles in the die, the definite variations in pressure were obtained. At each pressing the plunger was brought down and released three times in succession, the speed of the plunger being 1⅜ in. per second or 7 ft. per minute. The pressure used was shown by pressure gauge in the hydraulic line. The calculated pressure on the plunger head was found to check with

TABLE I — SEMI-VITREOUS ABSORPTION

PRESSURE LBS. PER SQ. INCH	TITLE NUMBER								AVERAGE
	1	2	3	4	5	6	7	8	
107	16.294	16.989	16.946	16.760	16.444	17.286	16.153	16.731	16.700
120	16.497	16.641	16.353	17.234	16.565	16.601	16.680	17.247	16.727
137	15.491	16.340	15.437	15.719	15.833	15.658	15.784	16.422	15.834
160	15.947	16.727	15.628	16.401	14.748	16.353	15.939	14.845	15.823
192	14.575	16.141	13.776	14.914	13.879	13.312	15.868	15.520	14.748
213	13.527	13.457	14.025	14.887	15.277	14.610	15.460	14.812	14.507
240	14.101	14.087	14.300	15.469	13.377	12.736	14.276	13.925	14.033
275	13.629	12.726	12.555	13.990	13.923	12.478	13.243	14.046	13.323
320	12.310	11.463	12.421	13.222	13.618	11.493	12.612	13.705	12.605
349	12.639	12.868	11.511	11.501	13.087	11.336	13.032	13.791	12.470
384	11.750	11.597	12.408	12.340	12.588	11.397	13.651	11.281	12.126
426	11.437	11.963	11.705	11.692	11.240	11.885	12.423	10.877	11.652
480	11.965	10.831	10.655	9.948	12.540	10.913	11.614	11.693	11.270
548	11.178	11.227	9.752	11.615	9.664	10.713	10.342	10.544	10.629
640	10.328	10.390	9.079	9.696	9.378	10.139	10.793	11.270	10.134
768	9.122	8.576	9.232	9.672	9.018	9.370	9.430	8.566	9.122
960	8.026	8.444	9.162	9.259	8.972	8.414	9.006	7.816	8.637
1280	7.386	7.974	7.816	7.480	7.694	8.242	....	....	7.756
1600	7.269	6.508	6.410	7.031	6.701	6.934	....	....	6.809
1920	6.312	6.448	6.638	6.376	6.527	6.393	....	....	6.446
2400	5.792	5.664	5.433	5.939	5.981	5.473	....	....	5.714
3840	4.392	4.500	5.165	4.617	4.416	4.555	....	....	4.607
4800	3.761	3.977	4.005	4.100	4.204	4.209	....	....	4.063

the reading of a static gauge placed under the plunger. Care was taken to insure practically uniform filling of the die.

After affording time for drying, each type of tile was fired to its temperature of maturity,

Vitreous to cone 11
Semi-vitreous to cone 7
Porous to cone 10.

Degree of density is shown by absorption of water during two hours boiling and twenty-four hours soaking.

Shrinkage was measured across face of tile using a micrometer screw, and the figures are given in terms of percentage of original dimension. Drying shrinkage was negligible.

Single determinations on tiles of the same pressure do not, in general, vary materially from the corresponding average result

TABLE II — SEMI-VITREOUS SHRINKAGE

PRESSURE LBS. PER SQ. INCH	TITLE NUMBER								AVERAGE
	1	2	3	4	5	6	7	8	
107	8.75	8.96	8.68	8.82	8.61	9.03	8.75	8.96	8.82
120	8.89	8.96	8.82	8.96	8.68	8.68	8.82	9.03	8.86
137	8.89	8.82	8.75	8.61	8.46	8.53	8.46	8.82	8.67
160	8.96	8.89	8.61	8.75	8.25	8.75	8.46	8.61	8.66
192	8.61	8.61	8.11	8.46	8.04	8.61	8.61	8.39	8.43
213	8.75	8.25	8.25	8.32	8.32	8.61	8.46	8.18	8.39
240	8.25	8.39	8.25	8.46	7.97	8.04	8.18	7.97	8.19
275	8.11	7.82	7.82	8.04	8.04	7.97	7.89	8.04	7.97
320	7.75	7.54	7.97	7.89	7.97	7.68	7.75	7.89	7.81
349	7.89	7.89	7.54	7.40	7.82	7.75	8.04	7.89	7.78
384	7.54	7.54	7.75	7.68	7.75	7.61	7.89	7.54	7.66
426	7.47	7.61	7.54	7.40	7.54	7.82	7.54	7.33	7.53
480	7.68	7.25	7.25	7.04	7.68	7.54	7.25	7.61	7.41
548	7.47	7.40	6.90	7.40	6.83	7.25	6.90	7.54	7.21
640	7.25	7.11	6.76	6.83	6.90	7.18	7.11	7.40	7.07
768	6.76	6.83	6.76	6.90	6.61	6.90	6.69	6.47	6.74
960	6.47	6.47	6.76	6.69	6.54	6.54	6.47	6.47	6.56
1280	6.05	6.19	6.26	6.05	6.26	6.33	....	....	6.19
1600	6.19	5.83	5.76	5.90	5.76	5.76	....	....	5.87
1920	5.76	5.62	5.48	5.48	5.76	5.55	....	....	5.61
2400	5.48	5.33	5.19	5.48	5.33	5.05	....	....	5.31
3840	4.77	4.91	4.91	4.91	4.84	4.91	....	....	4.89
4800	4.77	4.62	4.62	4.69	4.55	4.48	....	....	4.62

obtained. This is shown in Tables I and II, in which results of single determinations made on the semi-vitreous tiles are given as typical example.

In Table III the average figures for the three types are shown. From the values in Table III we obtain the curves in the Figures. It will be noted that for a given type the shrinkage curve is not plotted on the same scale as the absorption curve and that its zero is so located as to make comparison with the absorption curve convenient.

It is noted that the general form of the density curves is the same as that obtained by Prof. Parmelee on New Jersey fire clays. However, here it is noted that the effect upon shrinkage, instead of being unimportant, is very marked and compares with density in importance to the tile manufacturer. The shrinkage curve follows the absorption curve, showing greatest

TABLE III

PRESSURE LBS. PER SQ. INCH	VITREOUS		SEMI-VITREOUS		POROUS	
	ABSORPTION	SHRINKAGE	ABSORPTION	SHRINKAGE	ABSORPTION	SHRINKAGE
107	6.514	14.19	16.700	8.82	25.116	4.96
120	6.219	13.96	16.727	8.86	24.547	4.86
137	5.490	13.60	15.834	8.67	23.872	4.83
160	5.086	13.46	15.823	8.66	22.807	4.76
192	4.316	13.27	14.748	8.43	20.980	4.60
213	3.335	12.93	14.507	8.39	20.780	4.57
240	3.378	12.79	14.033	8.19	20.142	4.46
275	2.756	12.58	13.323	7.97	19.888	4.49
320	1.938	12.27	12.605	7.81	18.457	4.34
349	1.904	12.23	12.470	7.78	17.595	4.30
384	1.645	12.04	12.126	7.66	17.090	4.25
426	1.456	11.99	11.652	7.53	16.527	4.23
480	.740	11.58	11.270	7.41	16.333	4.05
548	.394	11.17	10.629	7.21	15.880	4.02
640	.168	10.85	10.134	7.07	15.738	3.96
768	.051	10.43	9.122	6.74	14.653	3.82
960	.025	9.85	8.637	6.56	14.523	3.77
1280	.011	9.33	7.756	6.19	12.782	3.70
1600	.007	8.82	6.809	5.87	12.269	3.63
1920	.005	8.41	6.446	5.61	11.441	3.65
2400	.004	8.04	5.714	5.31	10.740	3.40
3848	.007	7.52	4.607	4.89	9.668	3.41
4800	.003	7.19	4.063	4.62	8.738	3.18

range of values in vitreous body and least in porous body. It is, however, of interest to note the general agreement of the curves for the three types.

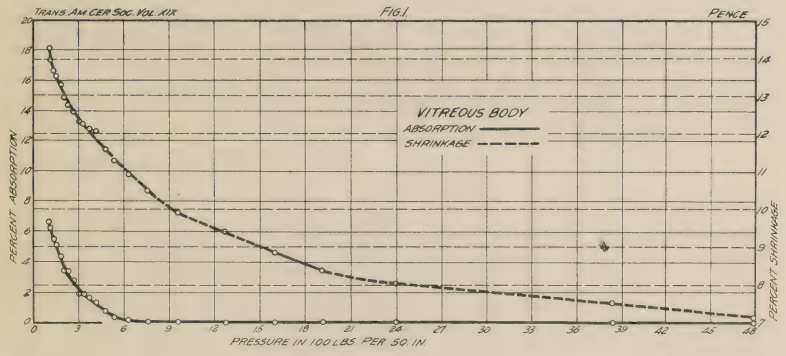
The volume shrinkage of the tiles did not change materially since tiles remained thicker with reduced pressure. But since shrinkage across face of tile is of vital importance to the tile manufacturer, it is this shrinkage that is given.

The point where further increase in pressure does not produce a proportionate increase in density is, as shown by form of the curves, at about 800 to 1,000 pounds per square inch, whereas Prof. Parmelee obtained a pressure of approximately 6,000 pounds per square inch at this point. We should here recall that in the latter case pressure was applied gradually, while here pressure is applied successively as in the process of tile manufacture.

The tiles of the porous body were glazed with bright white glaze and subjected to a crazing test. The difference between the various members was not marked. However, those receiving from 2,400 to 4,800 pounds pressure crazed slightly in advance of those pressed at lower figures. The difference was not great but was shown to exist by a number of check results on different series. As to the other members, crazing occurred irregularly and appeared to bear no relation to the pressure, the most porous tiles standing as well as the denser ones.

Thus, as applied to tiles, crazing of soft bisque would signify "soft" fire bisque, and not "soft" pressed only. This is also confirmed in practice from fact that in curved shapes those parts that tend to receive least pressure when tile is being pressed are the parts that show greatest tendency to shivering of the glaze.

Under practical conditions it would appear that the lower limit of pressure would be approximately 1,000 pounds per square inch, while upper limit might be 2,400 or higher, depending upon what difficulties may be encountered as to bursting or splitting of the tile in pressing, or blistering of vitreous body in firing. In general a better surface texture is obtained at the higher pressure than at the lower.


TRANS. AM CER SOC. VOL. XIX
FIG. 1.
PENCE
VITREOUS BODY
ABSORPTION
SHRINKAGE
PERCENT ABSORPTION
PERCENT SHRINKAGE
PRESSURE IN 100 LBS. PER SQ. IN.

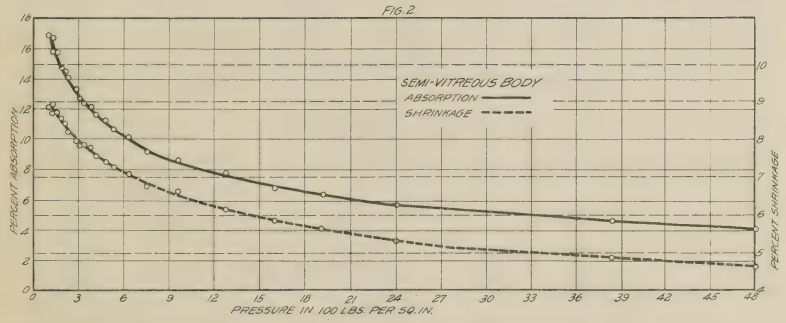


FIG. 2.
SEMI-VITREOUS BODY
ABSORPTION
SHRINKAGE
PERCENT ABSORPTION
PERCENT SHRINKAGE
PRESSURE IN 100 LBS. PER SQ. IN.

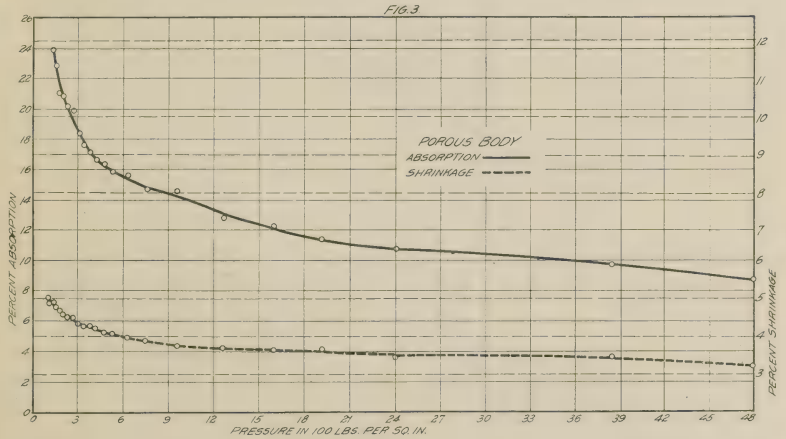


FIG. 3.
POROUS BODY
ABSORPTION
SHRINKAGE
PERCENT ABSORPTION
PERCENT SHRINKAGE
PRESSURE IN 100 LBS. PER SQ. IN.

From results obtained it would appear that a pressure of 1,800 to 2,000 pounds per square inch would be recommended as a satisfactory mean and one permitting of considerable variation of pressure in either direction without seriously impairing the quality or uniformity of the tiles.

DISCUSSION

Mr. Townsend: Mr. Pence's experiments check up with mine. I made a test pressing some tile by simply letting the weight of the lever come down on the dust and thus having the tiles so soft that you could hardly pick them up, and then I had tiles pressed to the extreme, the presser giving two extra bumps more than we usually bump them. Then these two lots of tile were fired at the same heat in both bisque and glost kilns. I then had them set on the wall probably 15 feet of each lot; and they stood there for a year, and on examining them after this lapse of time, some of the tile of each lot showed signs of crazing, but I found on counting the pieces crazed in each lot, a few more crazed in the hard pressed tile than in the soft pressed tile, and from this test my opinion has been that the crazing of the tile is due to under-firing the bisque and not to soft pressure.

Mr. Parmelee: I have been interested in the experiment of Prof. Pence and gratified to find out that his results are so nearly in accordance with mine. He has reported his in percentage of absorption; mine was reported on the basis of porosity. As far as fire clay was concerned, I experienced a good deal of difficulty because at higher pressures the material oozed out around the die, and therefore it did not seem to be advisable to get the shrinkage through the piece. I measured the shrinkage across the piece and it was practically negligible; perhaps I did not make that point clear in the paper. I would like to ask Mr. Pence whether he has measured the shrinkage across the finished piece under different conditions of pressure? There is another point on which I would like to have some information, namely: I have been told, on several occasions, that it is possible to change the hardness or density of the face of a tile according to the way in which the pressure is exerted, and I have also been assured that it would be possible to control the condition of either face or to

control condition of the faces as compared with the middle of the tile; that is, speaking of a thin tile. I can see, perhaps, some reason why a thick tile might be affected that way, but it is not at all clear to me that in an ordinary wall tile there should be a difference in the two faces, in density or hardness. Perhaps Mr. Pence or some one who has had similar experience can answer that question.

Mr. Pence: That is a very interesting question and one that is of vital interest to the tile manufacturer, because the tile manufacturer wishes to obtain uniform density throughout the tile; otherwise, as has been shown in this shrinkage curve if you have a different density on one side of the tile than on the other, you will have a badly warped tile. The method for correcting that is also indicated in this chart; that is, to use sufficient pressure to get the tile hard, as we say, throughout. We know that if we press the hand down in the snow, the snow will be dense next to the hand and nearer to the ground, it will not be affected much. The same holds true in pressing a tile; if the tile is insufficiently pressed, it will be dense near the moving plunger and not so dense near the base; but if the tile is pressed sufficiently hard, that is, if there is sufficient pressure used to transmit that pressure throughout the thickness of the tile, there should not be any material difference between the density of one side and the other, although I think that in all cases there perhaps is a slightly greater density near the moving plunger.

I might add that all shrinkages were measured across the face of the tile.

Mr. Parmelee: I found practically no difference.

THE ADVANTAGES OF CLAY STORAGE AND THE DESCRIPTION OF A SUCCESSFUL INSTALLATION

BY F. H. RIDDLE.

The Advantages of Clay Storage. Is the storage of clay necessary in the manufacturing of heavy clay products? The usual answer to this is: No, not if you can arrange your plant so that you deliver clay directly from the bank to the pans. There is no doubt but that this is true in a great many cases. However, there are many other cases, in the writer's opinion, where the using of the clay direct is not cheaper, when all the results are considered. It may cost a little more per ton to handle the clay, but when the lack of uniformity of the material, the resulting variation in handling, and the burning losses are considered, it is expensive not to store the clay.

No matter what the problems of manufacture are, so long as they are uniform, they can be handled in systematic manner, and the system gradually altered or improved so that better results are obtained. The minute the raw materials cease to run uniform, then the system is upset and trouble begins. Even if the lack of uniformity is known ahead of time, it is necessary to alter methods to meet the condition, and this means a great deal of trouble with the ordinary clay-working plant, and a lot of personal attention. Quite often the man in charge does not understand the cause of the sudden change, or how to correct the trouble, so that considerable money can be lost in a comparatively short time. If there is no warning of the trouble, and, for example, a burner takes down the wicket of a kiln and finds swelled ware, it means that all the ware in several other kilns is in similar condition, and that if he does not act quickly, all the rest of the ware in the kilns and on the floor will be giving him the same trouble. If it is a new kind of trouble which he has no knowledge of from previous experiences, then there are chances for heavy losses. Troubles of this sort

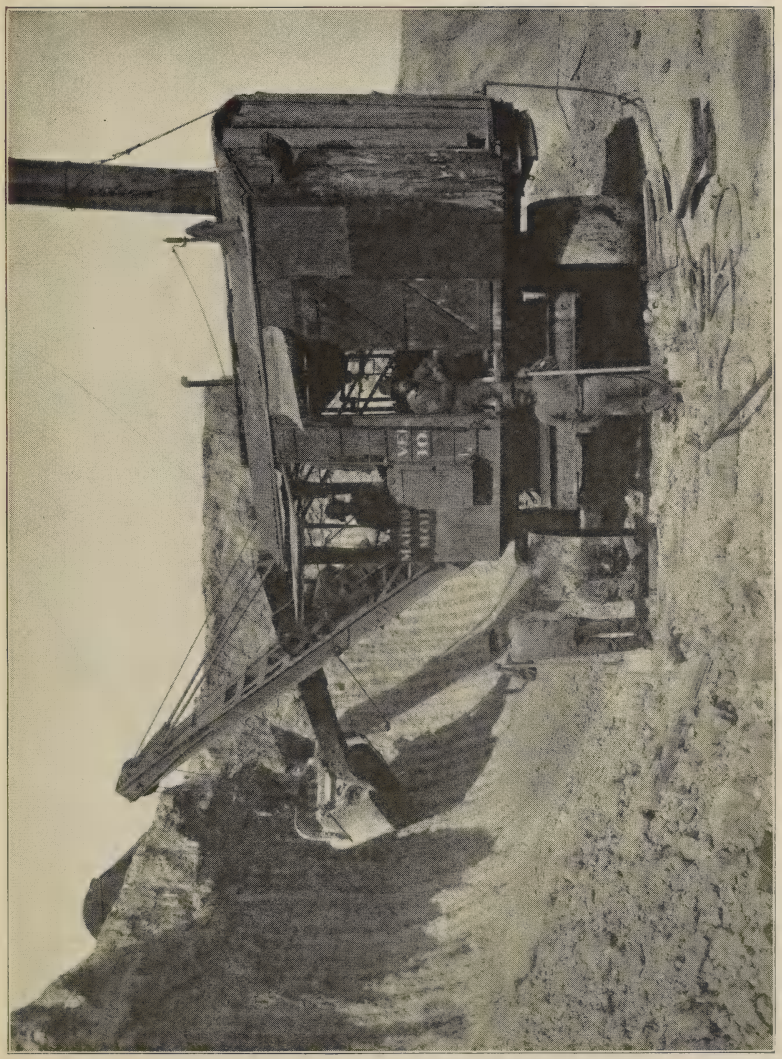


FIG. 1.

are not suppositions in practice; in fact, they are quite common, and in some plants so common that the managment is lead to believe they are part of the business, and must be expected.

If the clay bank varies from time to time so that certain firing conditions give blown ware, or cored ware, or both at one time, and later the ware is good under the same conditions, there will be a tendency on the part of the operator to find the safe burning method under the worst conditions, and burn accordingly. It is better to do this than to make a saving in the burning at certain times and then suddenly have heavy losses which will immediately counterbalance all the savings made. It is possible, on yards where the operator has the necessary knowledge, to use draw trials and vary the burning conditions to correspond to the clay conditions. This will mean changing the system and worrying about whether the burner or his helpers will remember the directions, etc. How much better it would be to have some means of getting a uniform mixture of clay from the bank so that the same method could always be used, and the systems of operating could gradually be altered so that the losses would eventually be reduced to a minimum.

The possibilities of this mixing of the clays from different parts of the bank depends largely, of course, on the local conditions, daily tonnage, etc. There are, however, a good many clay workers who would do well to see what the mining engineers and steel and iron operators are doing along these lines, particularly, when it comes to the question of storing and handling enormous tonnages. It is true that most of these operators are warranted in making large investment in plant and equipment on account of the enormous tonnages and high values of their products, but it is also a fact that, particularly in mining, some operators are handling very low grade ores in small quantities and doing it successfully. The usual reason is that they study their conditions thoroughly and equip the plants accordingly, after availing themselves of other peoples' experience.

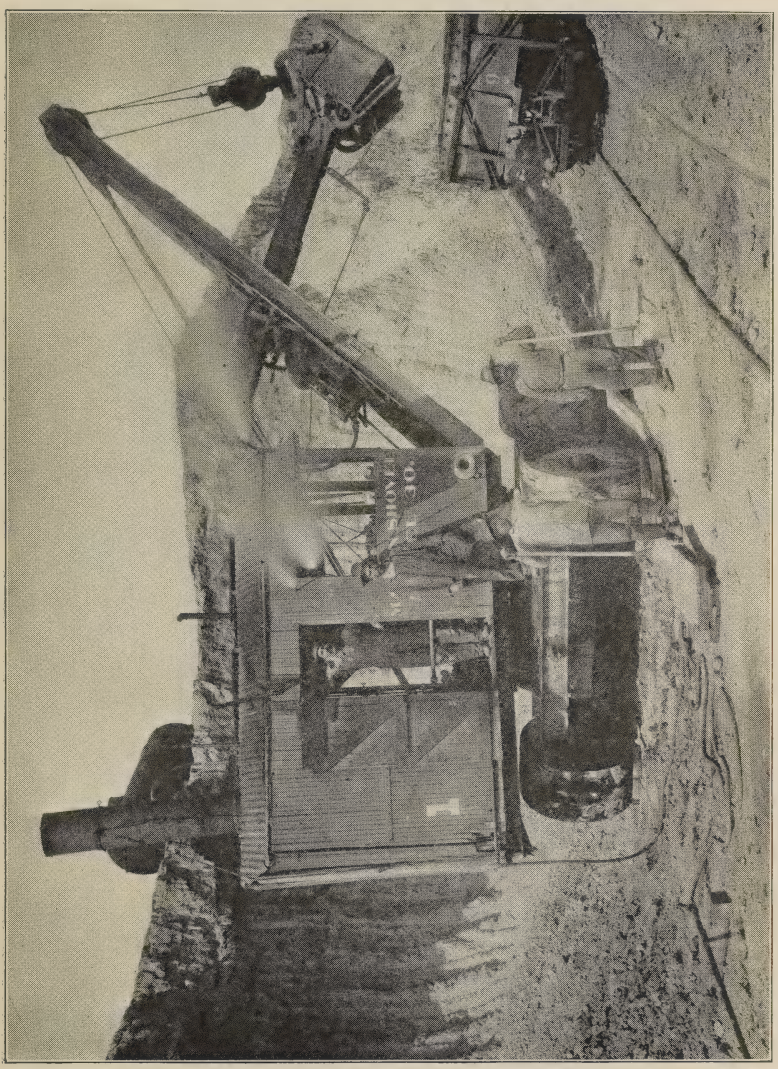


FIG. 2.

The writer has several plants in mind where the clay handling has been worked out by modern methods. The two plants, however, where this handling is done the best and cheapest, conditions being considered, are plants where the clay storage and handling equipment have been built after consulting with engineers who have made a study of similar equipments in other lines of manufacture.

The system which is described below is elaborate, and performs several functions which the ordinary equipment would not be called upon to do, and yet, the investment was warranted.

The storing of clay is not only an advantage from the standpoint of being able to mix clays from different parts of the banks to obtain uniform conditions, but from other standpoints as well. A clay, that weathers with storing, will, as a rule, behave much better in manufacturing, and particularly in grinding. Where a dense product is desired, a material that will grind in such a manner as to form a sufficient amount of fine particles of material to fill the spaces between the larger particles, will give a denser structure than where the same material is ground so that the large spaces are not so well filled with finer particles. Weathering will tend to accomplish this varied sizing in grinding as well as to produce greater plasticity. The writer knows of one factory manufacturing paving block from a No. 3 fire clay where the weathering of the clay reduced the rattler loss two percent. The extra handling of the weathered clay amounted to considerable, but could have been accomplished with but very little extra cost if the proper equipment had been used. This equipment could have been installed at a cost that would have warranted the investment.

Weathering also tends to dissolve and wash out soluble salts in many clays, and thus eliminates ingredients which produce objectionable scumming. This subject has been very thoroughly discussed by others and needs no comment here.

If the shed is built with a view of weathering the clay, and to save labor in handling, it can be built without a roof. The advisability of not using a roof would, of course, depend upon climatic conditions, quality of clay, etc. If it is desired

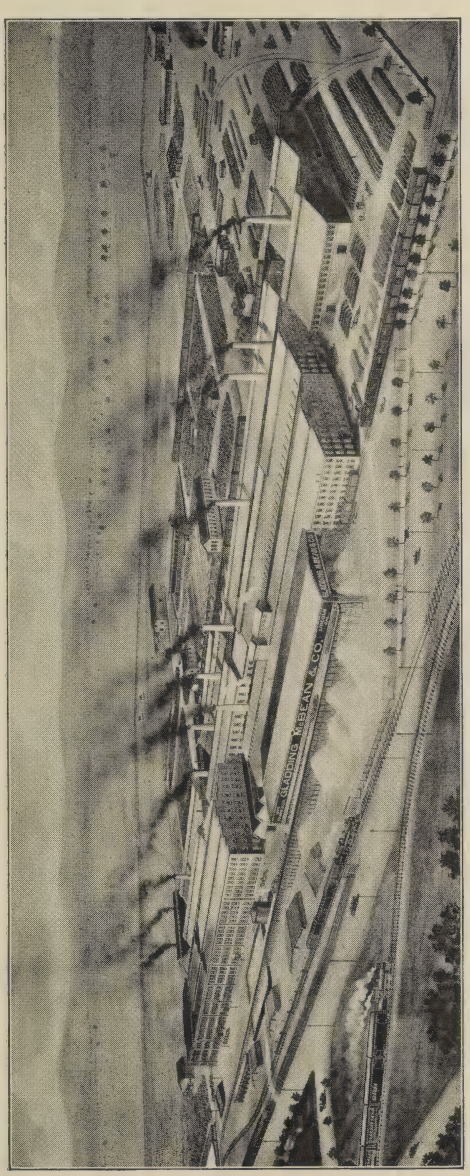


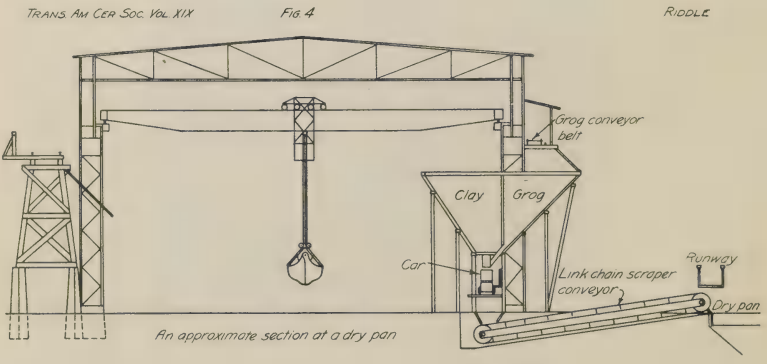
FIG. 3.

to keep the clay under cover and still weather it more rapidly than the ordinary exposure to air would do, this can be accomplished by the use of steam supply pipes laid along the ground, under the clay. These pipes are distributed as best meets conditions, usually 1 in. to $1\frac{1}{2}$ in. laterals running out at intervals of about 10 to 15 feet from the 2 or $2\frac{1}{2}$ in. feed pipe. The laterals have slits or small holes so spaced that the clay can be warmed from beneath, and the steam gradually work up through it. The steam, of course, is fed into the system at a low pressure. Along certain parts of the Ohio river the clay is weathered both by use of steam from beneath, and natural exposure above. Where both methods are used on the same pile, the weathering and disintegration is much further advanced on the bottom and heart of the pile where the steam has affected it, than on the outside where the weather has affected it.

DESCRIPTION OF A SUCCESSFUL INSTALLATION

The accompanying illustrations show a clay storage arrangement which is worthy of note. This arrangement accomplishes several things, the storing of the clay being only a small part of the work.

The plant which uses this system is like the majority of clay working plants in segregated districts, *i.e.*, it manufactures a wide variety of products, and is compelled to do so if



one of the aims of the concern is a large production, as it is very apt to be where the margin of profit is small.

The climate is mild, and there are several rainy months in the winter. This means that building and construction work go on practically the year round, and the factories can operate through the wet season. Not running the year round would mean the carrying of a large stock of finished ware to supply the trade during these months, and this difficulty would be increased on account of the variable demand.

This installation takes care of the clays and grogs for mixing several bodies for the manufacture of architectural terra cotta, sewer pipe, face brick of several shades requiring different mixtures, fire brick, hand-molded refractory shapes, flue lining, partition tile, terra cotta chimney pipe, drain tile, roofing tile, and some special products with a total approximate yearly production of 50,000 burned tons.

The actual piling of the clay into the shed for storing, the supplying of clays to the bins for mixing, the compounding of the bodies and feeding of the three dry pans is accomplished by three men, and gives them, in addition, some time to take care of cleaning up, small pan repairs, and similar work.

The custom in several places where the clay is stored near the pans is to have seven pan-wheelers for two pans. This with no special mixing, and from small stock piles where the wheel is comparatively short. The shed in question is 360 feet by 75 feet, and in the fall is filled from one end to the other, so that it is easy to see what it would mean if pan-wheelers were used, particularly when every product requires a mixed body. If this clay was stored in piles, by hand, it would mean the use of two or three times as much area with correspondingly long wheels, on account of the inability to pile to the enormous height to which the clay can be piled with the overhead carriage and bucket. The amount of personal attention each wheeler would require to prevent errors in mixing, and the roundabout routes they would have to take to get the several clays would also increase the expense.

When this particular unit was put in operation the cost of handling of the clay to the dry pans was reduced about two-

FIG. 5.

thirds over the old system. The real reason for the storage shed was to make it possible to run the year round, and have dry easy-grinding clay at all times. The system, then, not only made it possible to run the year round, but also made a big operating saving.

With labor conditions as they are in the East at the present time, an installation of this sort would represent a still greater saving in actual money, not considering the scarcity of men and delays from this cause.

Operation of the System. The clay is delivered to the shed by several methods, depending on the location of the pits, etc. The only requirement is that it be placed somewhere under the edge of the shed where the bucket can reach it to pick it up to deliver it to the storage piles. The bulk of the clay is mined with a No. 30 Marion steam shovel at the big clay bank, and loaded on four cubic yard capacity dump cars, and hauled down to the plant over a 3-foot gauge industrial railroad. Figs. 1 and 2 show the clay bank and method of mining and loading. Fig. 3 shows a general view of the plant from the direction of the clay bank. Bearing in mind that the clay storage shed, which is shown in the foreground, is 360 feet long, one can get an idea of the size of the plant. Also remember that three men handle the clay. Figure 4 shows a cross section of the clay storage building. On the upper left is the trestle from which the clay is dumped down into the shed from cars. The bucket then picks it up and puts it in a storage pile. Fig. 5 shows the trestle and shows the clay being dumped from the cars into the shed. Fig. 6 shows the bucket with a load of clay taken from the small pile which was dumped off the trestle. This clay is being taken to one of the large storage piles in the background. It is very easy to see from the cuts how flexible the arrangement is, and the enormous height to which the clay can be piled. By comparing the pile at the left which was dumped off the trestle, with the pile in the center which is still low compared with what it will be when filled out, one can get an idea of the volume of material that can be stored compared with what could be done if the clay was piled by use of wagons

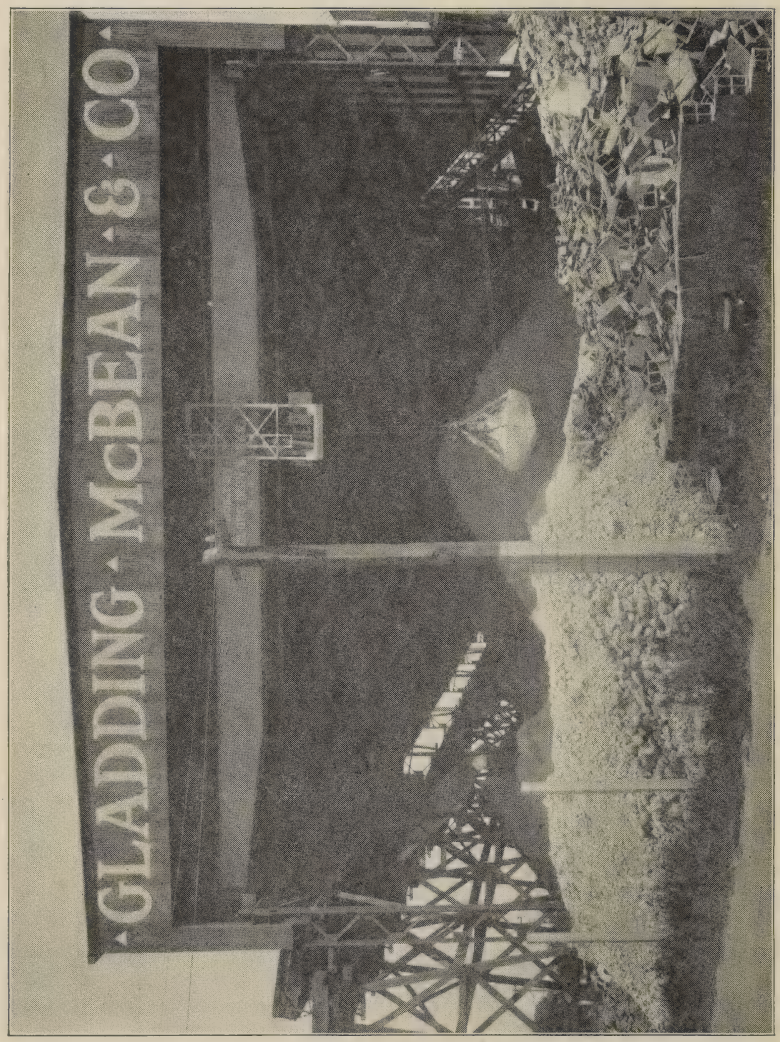


Fig. 6.

alone, or even what can be done compared with dumping off a trestle and leaving the clay there.

When the clay is to be used, it is picked off the storage pile and put into an overhead bin at the right, as shown in Fig. 4. There are series of these bins running along the side of the shed. Each one is slightly wider than the bucket so that it can be filled conveniently. Fig. 7 shows the open bucket in position over one of the bins. Note the arrangement of the operator's platform and how the bucket goes up beside him, using a minimum amount of head room and making it easy for him to see what he is doing. This work is done by the first of the three men mentioned.

The grog bins are right beside the clay bins, as shown in Fig. 4. Fig. 8 shows the grog bins from the outside and the incline conveyor belt going to them. All the grog is collected near the gyratory crusher shown in the left foreground. As a rule the grog materials are left near the kilns from which they are drawn, and then hauled direct to the crusher in small dump carts so that there is comparatively little labor required to feed the crusher.

The crushed grog from the gyratory crusher dumps on the conveyor belt and is carried up the incline and dumped into any of the several storage bins, as desired. The dumping is done by use of a standard type two pulley tripper, which can be shoved along a track over any bin desired. This gives us the clay and grog in the overhead hopper bottom bins ready for body mixing.

This mixing is done in diaphragm, or measuring, cars which are electrically driven along a track under the hoppers of the supply bins. They are coupled together and operated as a unit. The operator rides on one side of the cars on a platform which runs the entire length of the cars. He has a controller rod which also runs the entire length of the cars so that he can throw the power on or off from any place he stands. The compartments can be made any size desired, so that the right amount of material can be used. It is not unusual to see the operator feeding three different pans, each one with a different body. To make this possible the two long mixing

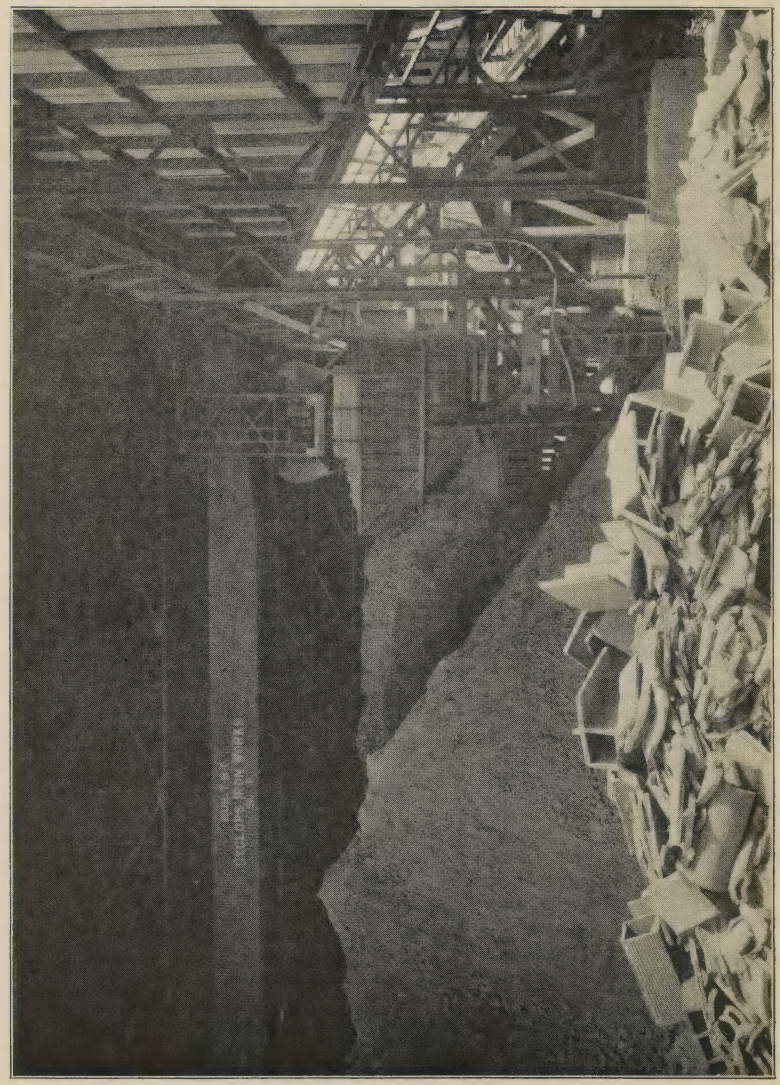


FIG. 7.

cars are used, so that all of the required sizes of compartments can be available without stopping to alter any between each charge. The compartments for one body are arranged so as to be close to each other, and the bottom dumping arrangement, as described below, is arranged in sections so that the entire bottom does not have to be opened up to discharge. Figure 9 shows the convenient arrangement of the car and spouts and the method of opening and closing the spouts. To make a charge, the operator runs his car along until the proper compartment is under the proper spout and fills the compartment level-full; then to the next, etc. Note the names of the material in each bin plainly printed over the operator's head, directly opposite each spout. These names are partially hidden behind the pipe in the cut. Also note the framed charts at the back of the car. These can be seen right under the left spout. They are attached to the car and are charts showing the composition of the different bodies, for the operator to refer to. The grog spouts are not shown in Fig. 9 as there are not as many grog bins as clay bins. Fig. 4 shows the way the spouts feed from grog bins to the mixing car. On account of the dryness and previous crushing of the grog, it runs through a small spout with comparative ease.

When the necessary compartments are filled, the car is run along the track until it is directly over a hopper. There are three of these hoppers, each one emptying on to a conveyor and each conveyor feeding into a dry pan. Fig. 4 shows a section with the conveyor which feeds the pan. Fig. 10 shows the end of the diaphragm car and the dump bottom. The bottom is let down by means of a trip, and after dumping, is lifted back into position by means of a ratchet lever arrangement, as shown on the right end of the cars in Fig. 9. Figure 10 shows the operator's platform, and the trolley wires on the left which supply current to operate the motor which drives the car.

The operating of the measuring cars can be the source of considerable extra work unless it is handled so as to load the clay farthest from the dump first, and then work towards the dumping point. If the dumping point happens to be midway along the line of bins, the cheapest method is to go to the end

Fig. 8.

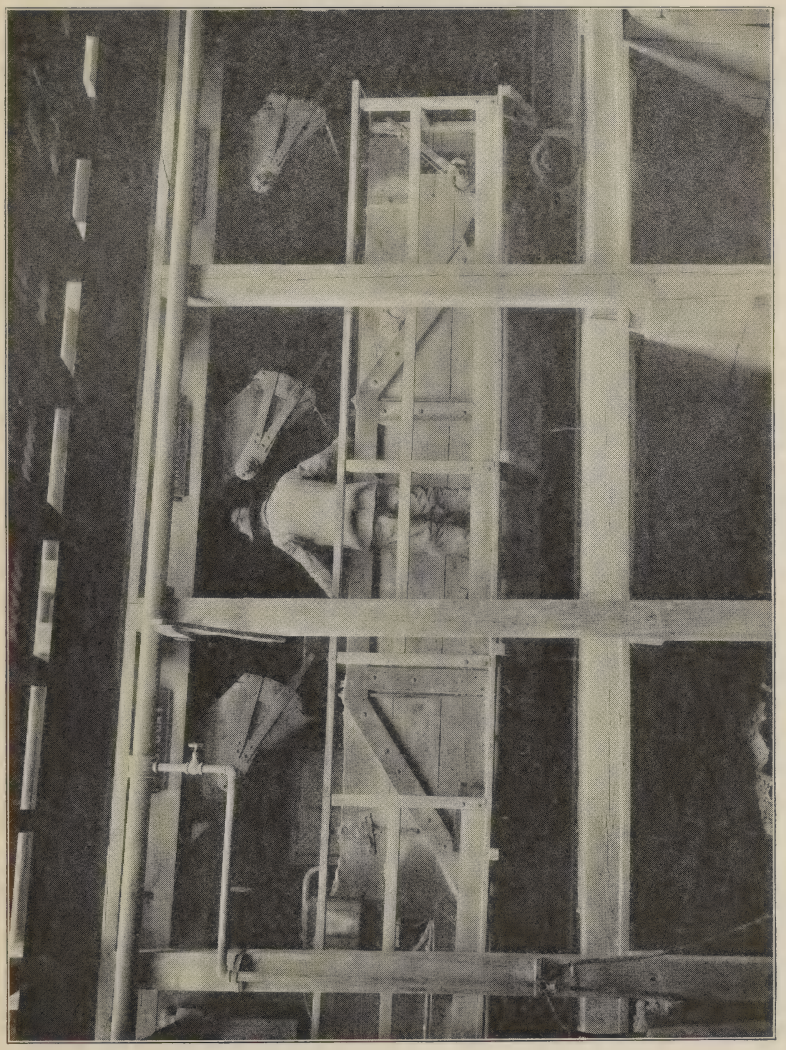


FIG. 9.

where the smallest load will be put on, then down the other way to the farthest bin necessary for the mix, and work back to the dumping point. It would save considerable extra hauling if the load obtained at one end of the system could be dumped on the way over the dumping point on the way to the other end, but it would cause loss of time lifting the bottom and would result in feeding the pan with an uneven mixture of the materials. The above work is done by the second of the three men mentioned.

Fig. 11 shows one of the dry pan installations with the conveyor leading from the dump, up a gradual incline to the pan. The tail end of the conveyor is far enough below the measuring car so that the hopper sides can taper from a distance equal to the length of the car section at the top, down to a distance equal to the width of the conveyor at the bottom. This thoroughly mixes all the different materials and carries out an even mixture on the conveyor, no matter what amount is taken. The pan feed conveyors are controlled by an operator who walks along a bridge over the pans as shown in the back of Fig. 11, and in section on Fig. 4. This man feeds all the pans. The system used in the conveyors is to have a metal lined conveyor box, and to pull the clay mixture along this box by means of double chain swivel flights. The iron flights are about 6 in. high and 24 in. apart. The double chain flights on the return side are shown on the lower part of Fig. 11. The pan feeder sets the pace, and it is the mixing man's business to keep the conveyors supplied with body, and the bucket man to keep the bins over the car full of clay, and attend to piling the incoming clay for storage as time permits.

The screened and ground clay storage feed system inside the plant is equally interesting and works very well. Considering that these bins have to take care of different clays from different pans and supply several different kinds of machines, including two sewer-pipe presses, two auger machines, a tile press, and various tempering machines for hand mold work, it can be readily understood that it required considerable study to work the system out. That it does work is very evident from

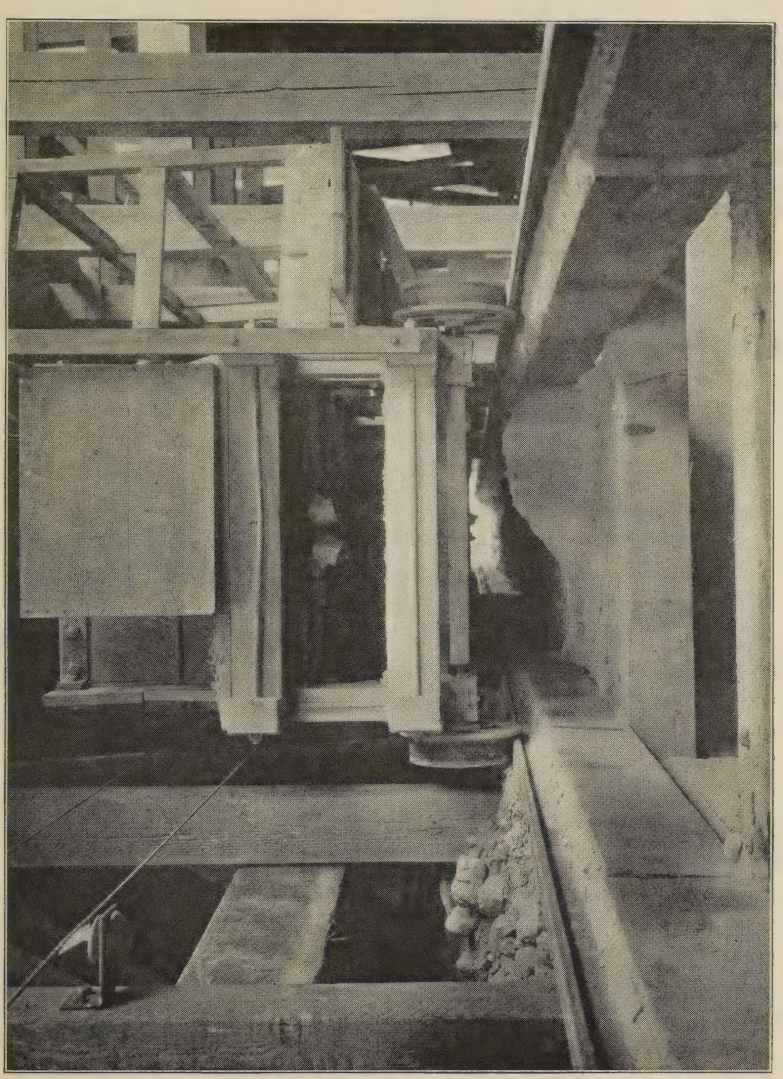


FIG. 10.

the fact that one man can take care of screens, bins, feed chutes, etc., and have time to clean up.

Mixing Necessary to Obtain Uniformity. No mention has been made of the thorough mixing the clay receives in the process. The steam shovel, of course, gives a good average sample of the vertical cross section of the bank. Dumping off the cars and re-piling in the shed gives an extra mixing, and in taking from the piles and putting into the overhead bins it is possible to take from extreme ends of the piles, so that the clay from various parts of the bank is mixed together. This mixing of the clays from different parts of the bank is a very important advantage, and one that would be a wonderful advantage in a great many plants that have variable clay banks. A system of this sort also permits the economical use of a great deal of grog that otherwise might go onto the dump, as it does in so many plants in some parts of the country.

There is no doubt that there are some plants fortunately situated so that the storage of clay is not necessary and where the clay is hauled directly from the mine to the gravity bins, so that it can be fed direct to the pans. On the other hand, if the matter were investigated thoroughly, and losses studied more carefully, the writer believes that there are cases where the operators would find that the actual cost per ton of marketable ware could be lessened by installing storage systems; *i. e.,* they would more than save the extra cost of handling clay, in the higher percents of marketable ware they would get due to having uniform material to work with, and being able to better systematize their burning, etc.

Suggestion for Simple Installation. There are a good many overhead bucket conveyor systems in use in various industries, and these systems are comparatively simple and do not represent a large investment. Where it was desired to get a uniform mixture of clay from various parts of a bank, it could be done without great expense by having an equipment similar to Fig. 12. This would eliminate pan wheelers and leave the clay exposed so it could weather quickly without the use of steam supply pipes beneath. In the case of heavy shales, it might be necessary to install a crusher, but this would be war-

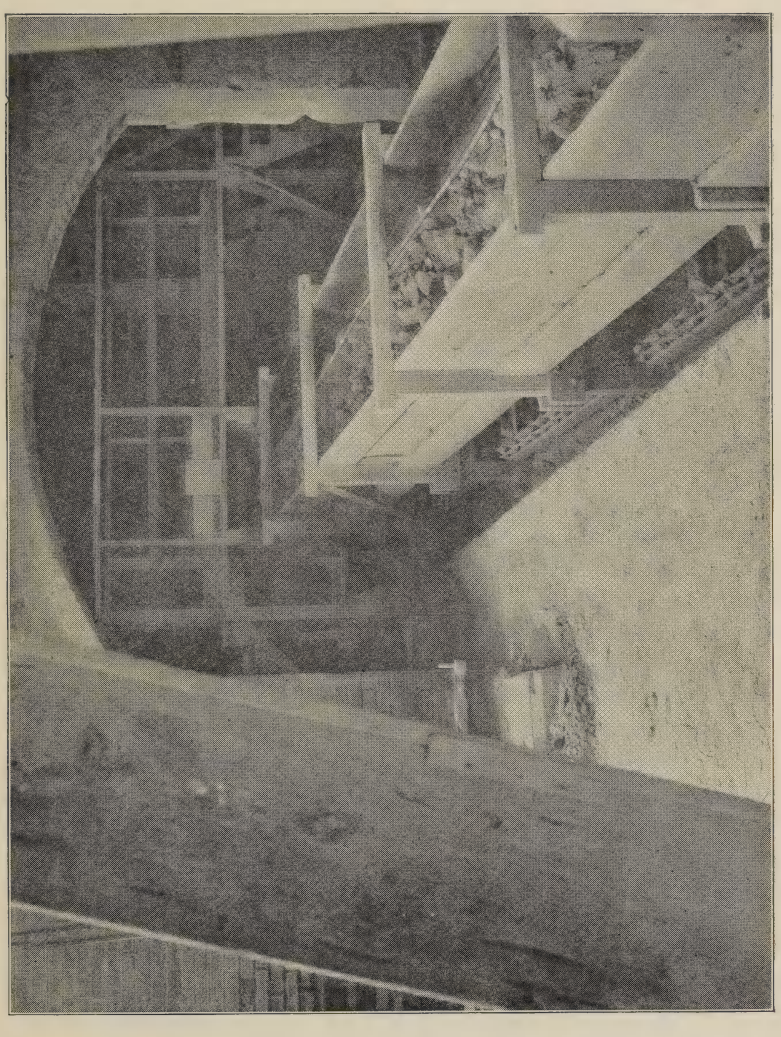
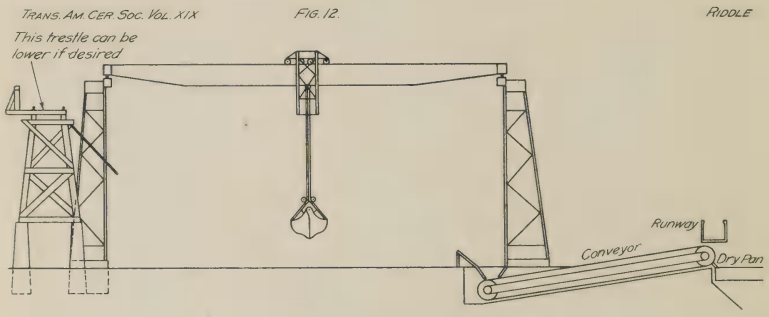


FIG. 11.

ranted as it would eliminate the usual sledge-hammer labor and heavy pan duty that so many plants are now needlessly contending with.

In conclusion, the writer wishes to thank Gladding-McBean and Company for permission to describe their system, and for the photographs furnished.



DISCUSSION

Mr. Blair: There is just one little point in connection with this paper that I would like to call attention to and not by way of criticism of such installation. If you will notice that suggestions for installations of this character nearly always come from industries or from the portion of the clay industry where the price per ton of material handled is the highest price obtainable. The portion of the industry, that needs such an installation the most, those handling heavy tonnage at a low price, is the one without it. Whether the one has a bearing on the other, whether they cannot get the money by selling paving block, for instance, at $11.50 per thousand or $2.10 per ton as compared with the terra-cotta plant that sells at $35 or $40 a ton or an iron and steel mill that runs from $37 to $100 a ton for their product — whether the price per ton of the material to be handled has not something to do with the lack of installations of this character, is a question.

Mr. Riddle: If Mr. Blair will study the detail of the paper as to the number of men required to operate this system as compared to the usual number around any brick plant where they have the same climatic and clay pit conditions, I think he will

find that there is a saving in that particular operation. If there is a saving in the operation it would seem to the writer that the investment was warranted regardless of selling cost. As stated, this particular installation was used in the manufacture of several products including brick, sewer pipe, partition tile, etc., as well as terra-cotta.

Mr. Moore: I am familiar with a paving brick plant that is handling a product not quite so expensive as this, but they are obtaining an average price of $18.75 a thousand for their block, and their installation as far as the weathering conditions and air system is quite similar except that it did not have the clam shell distribution feature, it is all handled by belt conveyors, dumped in different portions, and the pickup is done by underground conveyors. I should say that the installation cost within probably 20 percent as much as this, and they could not operate very well without it.

Mr. Binns: I want to ask a question with regard to nomenclature. The title of Mr. Riddle's paper, was "The advantage of a clay storage," and he used the term "weathering." Is storage under cover weathering in the proper sense of the term?

Mr. Riddle: When I spoke of the question of weathering, I described a simple installation where you would use a series of poles to support the tracks for the conveyor. In that case there would be no roof, and that would be a cheaper arrangement. The point I mentioned in this first one, the elaborate system, was that they were in a country where it rained in the winter time and required the cover to keep the clay dry. There is no doubt, however, that weathering can be accomplished to some extent with the clay covered. Where steam pipes are used beneath, this weathering can be accomplished very well.

Mr. Binns: I thought it was the advantage of weathering, the solution of soluble salts, etc., and I wanted that cleared up.

Mr. Riddle: The design of the system should be made according to the local conditions. If dry storage alone was desired, a cover should be used. If the system is to be designed to expose the clay to the elements and wash out the soluble salts, then, of course, the roof would be omitted. The term weathering, as I have used it, means the disintegration and softening of the lumps.

Weathering does not necessarily include the washing out of any soluble material.

Mr. Binns: Some years ago there was a case raised of a buff brick developing a brown stain by the clay being stored under dry cover. The experiment of turning out the clay into the open was tried, and the brown stain disappeared. So far from storing under dry cover eliminating stain, it is quite possible and probable that it will increase stain rather than diminish it.

APATITE, A SUBSTITUTE FOR BONE ASH

BY N. B. DAVIS, OTTAWA, CANADA

In Eastern Canada there are large deposits of the mineral apatite — $(CaF)Ca_4(PO_4)_3$ — very little of which is being mined at present. It occurs in large, coarsely crystallized masses associated with mica and pyroxene in rocks of Pre-Cambrian age.

A number of years ago, between 1883 and 1891, the annual output was 25,000 tons, but with the discovery and active exploiting of the sedimentary phosphates of the Southern States, Canadian apatite lost its position as an important source of phosphate for the manufacture of commercial fertilizer. Hence the Canadian mines closed as apatites mines, but later some of them reopened as mica properties. In the meantime large stocks of very pure apatite accumulated on the mica mine dumps, in the hope of some use being found for them. Only a very small amount has been absorbed in the manufacture of phosphorus and pure salts of that element, and for increasing the phosphorus content of pig iron.

It is important, therefore, that some new use be found for this material and what would be more natural that to use it as a substitute for bone ash in the manufacture of bone china, and for opacifying enamels.

Turning to the literature on bone china, the English potters have the credit for developing this type of ware; and how simple is the reason given for the first English use of bone ash in a body. According to Mellor,[1] the information was sent to Europe from China by a traveller, that the Chinese potters had said European potters might as well try to make a 'body without bones' as to try to make porcelain with nothing but the pegmatitic flux which had been carried to Europe by Eastern traders. What more natural than 'bone' should have been taken literally.

Edwards[2] states that "the value of bone for pottery purposes is determined by the percentage of phosphate, and also of

[1] Mellor, *Trans. Eng. Cer. Soc., Vol. V*, p. 79.
[2] Edwards, *Trans. Eng. Cer. Soc.*, 1904, p. 32.

the deleterious conditions such as carbonaceous and siliceous matter and iron". He gives the following as an analysis of an average quality of bone ash.

	percent
Tricalcium phosphate	85.25
Carbonate lime	2.88
Carbonate magnesia	2.45
Fluoride lime	1.65
Ferric oxide	0.32
Insol. Silica	4.57
Loss (water and carbon)	2.85
	100.00

In experiments with a synthetic bone ash made up in two ways, (1) with commercially precipitated phosphate, and (2) with calcium phosphate precipitated and purified by himself, Edwards found that the commercial material gave poor results because of the presence of alkalies, while the pure phosphate gave bodies as translucent, and showing no more fusibility or warping than the ordinary bone mixture.

"It would seem from this that the reason why Mr. Moss and others, in experimenting with artificial phosphate, found it had not the holding-up power of the phosphate obtained from bone, was that the phosphate used was impure. Phosphate obtained by precipitation from solutions of calcium chloride and sodium phosphate, unless very well washed, contains alkali, which of course makes it fusible. The commercial phosphate which I used, when fired alone through china biscuit, was fused quite hard."

"It would, therefore, appear that the cellular or fibrous structure of bone, to which is sometimes ascribed the permanency of form during firing of the china body, has no action whatever."

The important point to be noted in the above quotation is that pure calcium phosphate (free of alkalies) gave as good results as the commercial bone ash. Of course alkali-free chemically prepared phosphate would be too costly to be commercial, but this would not be true of the alkali-free mineral phosphate.

In answer to a question after reading a paper on "Bone China Bodies" before this Society in 1905, Watts[3] stated that he had tried making bone china from phosphate supplied by a fertilizer company but failed to get results. The discussion did not bring out the composition of the fertilizer phosphate, but it must have been impure. Apparently Watts never tried apatite as pure as the Canadian material.

The Canadian apatite, as it occurs in the district north of Ottawa, is usally pale green in color and of two types; massive and granular (sugar apatite). It occurs in large masses in pyroxenite rock. The mineral association is very similar to that of feldspar; except that in this case, apatite assumes the principal role, mica, feldspar, and pyroxene being the principal accessory minerals. Some pyrite is also present but it is usually very small in amount.

A number of analyses of typical apatites of the mines of the Ottawa district are given in the following table. The analyses were made by Mr. F. W. Connor of the Mines Branch, from the standpoint of the requirements of the fertilizer industry. Iron and alumina are given together, and iron oxide probably averages half the amount.

Analyses of Apatite

	NO. 15.	NO. 16.	NO. 17.	NO. 18.	NO. 19.
SiO_2	0.48	1.80	0.64	0.06	0.36
Fe_2O_3 }	1.00	1.30	1.30	0.72	0.72
Al_2O_3 }					
CaO	54.20	53.30	54.4	55.7	55.6
MgO	0.35	0.28	.31	.20	.33
Na_2O }	.77	.64	.88	.80	.25
K_2O }					
H_2O	.32	.36	.12	.28	.20
Cl	.44	.40	.67	.65	.50
F	3.30	3.20	3.30	3.10	3.00
CO_2	.66	.00	1.75	....	....
P_2O_5	39.60	40.15	37.50	39.24	39.39

No. 15. Massive reddish-gray apatite, McClelland mine, north lot 10, range 14, township of Hull, Que.

[3] Watts, *Trans. Am. Cer. Soc., Vol. VII*, p. 231.

No. 16. Dark reddish-brown massive apatite, Scott mine, lot 14, range 9, township of Hull, Que.

No. 17. Light gray-green sugar apatite, Rainville mine, east half of lot 15, range 8, township of Templeton, Que.

No. 18. Massive blue-green apatite, High Falls mine, lot 3, range 4, township of Bowman, Que.

No. 19. Green apatite, Blackburn mine, lot 9, range 11, township of Templeton, Que.

Large samples of both sugar and massive varieties of apatite were secured from the Blackburn mine for testing in a bone china body. Each sample was broken down and ground to pass 200 mesh, care being taken throughout the process to avoid contamination by iron.

Binns[4] gives the following as the general range of body composition for bone china.

	percent.
Bone ash	42-32
Feldspar	15-19
China clay	33-35
Flint	10-14

From this range, four bodies were calculated to have the following composition, substituting the ground apatite for bone ash. English china clay, Canadian spar and American flint were used.

Apatite China Bodies

No.	*1.*	*2.*	*3.*	*4.*
Apatite	42	39	35	32
Feldspar	15	16	17	19
China clay	33	34	34	35
Flint	10	11	14	14

Each batch was mixed and ground wet in a ball mill for 3 hours, the slips brought to the proper consistency, and, after standing in jars for a week, cups were cast in plaster molds.

The test pieces were burned in saggers in a commercial floor-tile kiln to cone 9. The cups were not supported, but set to show

[4] Binns, *Trans. Am. Cer. Soc., Vol. XII*, p. 176, (1910).

any deformation. After burning, all the cups were slightly deformed, but not badly considering the thinness of the walls. Had they been set in supports as is the practice in burning bone china, the cups would have been perfect.

All four bodies showed good translucency and color, but the translucency was best in Number 4.

In conclusion it may be stated that this paper is but preliminary to an extensive investigation of the subject and is presented here to bring the matter to the attention of the society and bring out helpful discussion from those interested in bone china.

NOTES ON THE USE OF SULPHURIC ACID IN THE SEDIMENTATION OF KAOLINS[1]

BY H. G. SCHURECHT

The use of sulphuric acid for neutralizing the sodium hydroxide in the purification of kaolins with alkalies has in some cases caused the kaolin refiners considerable trouble. The common troubles reported are the following:

(1) In some cases the plasticity of the kaolin after it had been treated was much greater than it was originally.

(2) A black scum appeared on the kaolin upon drying. As one of the commercial requirements of a paper clay is to have a clean white color, this defect would in some cases make the kaolin unfit for the better grades of paper.

The causes of these troubles were studied in order to outline precautions necessary to overcome these difficulties and to obtain from the crude kaolin the highest possible grade of product. This work has already progressed far enough to show that, in some cases, the troubles are caused by adding too much sulphuric acid.

Previous Work. Probably one of the first persons to notice the flocculating effect of sulphates was Förster[2] who noticed that the Ca-ion dissolved from the plaster molds hindered somewhat the deflocculating effect of sodium hydroxide. He therefore recommended the use of sodium carbonate in the place of sodium hydroxide thereby precipitating the calcium as calcium carbonate.

Hirsch[3] found that soluble sulphates were not absorbed by the kaolin or clay in the slip. Rieke[4] found that in the case of iron and aluminium sulphates the iron and aluminium are ab-

[1] By permission of the Director of the U. S. Bureau of Mines.

[2] Förster, F., Ueber das Giezsen des Tones: *Chem. Industrie*, 28, 1905, pp. 733-740.

[3] Hirsch, H., Verhalten von Ton in Salzlösungen, *Tonindustrie-Ztg., Jahrg. 28*, 1904, pp. 491-493.

[4] Rieke, R., Ueber die Wirkung löslicher Sulfate auf Kaoline und Tone: *Sprech. No. 51*, 1910, p. 757.

sorbed by the clay probably as hydroxides while the sulphate radical remains in solution.

Mellor, Green and Baugh[5] found that calcium sulphate thickens a slip while potassium sulphate and potassium bisulphate first make a slip more fluid and then thicken the same.

Rieke[6] found that magnesium sulphate, calcium sulphate, iron sulphate, zinc sulphate, copper sulphate, cobalt sulphate and aluminium sulphate increase the viscosity of a Zettlitz kaolin slip. Sodium and potassium sulphates increase the viscosity when added in small quantities and then with larger additions decrease the viscosity of the slip.

CLAY WASHING PRACTICE

Clays are usually washed by one of two methods in the United States. In the first method the clay is put in large tubs filled with water, and the clay is disintegrated by revolving arms. By this method most of the coarse material like sand and coarse grains of mica and feldspar are removed. The clay with fine grains of mica, feldspar and quartz remains in suspension and is drawn off into the settling tanks. Another method very similar to this consists in using a large cylinder, closed at both ends, which is set in a horizontal position. Iron arms rotating about a horizontal axis break up the clay lumps and the fine particles of clay are carried off by a current of water while the coarser material remains in the cylinder. The speed of the current must be so regulated as to remove only the fine material, and at the same time it should not be too slow for in this case the output would be too low. This method is not continuous for it has to be stopped from time to time in order to remove the coarse sand from the cylinder.

The method[7] in more common use consists in putting the clay in a clay washer. This consists of a rectangular box in which arms rotate about a horizontal axis and help to disintegrate the clay. It is common practice to use two washers allow-

[5] Mellor, J. W., Green, S. A., Baugh, Studies of Clay Slip: *Trans. Eng. Cer. Soc. Vol. 6*, 1906–7, pp. 161-170.
[6] Reike, R., *op. cit.* p. 757.
[7] For fuller details see Watts, A. S., Mining and Treatment of Feldspar and Kaolin: *Bureau of Mines Bull. 53*, 1913, pp. 72-78; Reis, H., Clays of Maryland: *Maryland Geological Survey*, 1902, pp. 271-276; Sproat, I. E., Kaolin Refining: *Trans. Amer. Cer. Soc., Vol. XVIII*, 1916, pp. 767–811.

ing the material to pass from the first washer into the second. When sodium salts are used to deflocculate the clay they are usually introduced in the second washer. From the washers the clay passes to the sand wheels which consists of wheels bearing iron scoops which operate in narrow tanks, the sand being scooped from the bottom of the tank and thrown outside. Two sand wheels are generally used, the clay then passing on to a series of troughs.

The sand trough is about 20 to 30 feet long and about 2 feet wide and is placed absolutely level. A dam 4 to 8 inches high is put at the outlet to assist in decreasing the flow thus allowing the coarse sand to settle and preventing it from getting into the mica troughs. This is removed with a shovel by a workman. The square tank which is used in the place of the sand trough in some places consists of a tank 6 feet long, 5 feet wide and 1 foot deep. The outlet is placed either at right angles to the intake or at the same end as the intake. The sand thus deposited is removed by shovel.

The clay now passes into the mica troughs which remove the mica and finer material. These consist of U-shaped troughs usually 1 foot wide and 1 foot deep, the total length being about 700 feet. In order to utilize less space these are broken up into lengths about 40 to 50 feet, which are arranged parallel and the slip passes through the same in a zigzag course. The flow is regulated by either a pitch of 1 inch between end and end or by building the troughs level with a drop of 1 inch between the troughs. The impurities deposited are removed every 5 hours during which time the washing is necessarily stopped. If the sediment is not removed the channel becomes narrow, thereby increasing the rate of flow of the slip. This would carry the coarser material farther along and make the product less homogeneous. When sulphuric acid is used to neutralize the alkalies in the slip, it is sometimes added to the slip at the point where it leaves the floating troughs. After the sulphuric acid is added the slip is run through a long narrow trough 1 foot wide, 1 foot deep and 50 feet long. This trough allows the sulphuric acid to become thoroughly mixed with the clay slip.

The slip now passes through the screens which are covered with a copper screen cloth. An excess of sulphuric acid would attack the screen reducing its life. The stationary screen which is commonly used consists of two or three wooden frames (about 4 inches high) covered with copper cloth and arranged so the upper screens overlap the lower screens. The material which overflows from the upper screen flows into the lower screens through openings 2 inches wide across the lower end of the upper screen. The revolving screen consists of a cylinder covered with a fine wire screen which is tilted at a slight angle from the horizontal. The slip being fed in at one end is separated from the coarse material which slowly works towards the outlet at the lower end of the screen.

The fine material which goes through the screen passes into settling tanks in which the slip stands until the clay has settled sufficiently to remove the excess water. The excess water is removed, and the slip is then passed into an agitator which is similar to a blunger. The slip, which is kept homogeneous by the revolving paddles of the agitator, is then pumped through filter presses. The clay is then dried by open air driers, steam driers, or tunnel driers.

Materials Studied. Three kaolins were studied in this work: (1) a kaolin from Gordon, Georgia; (2) a kaolin from Edgar, Florida; (3) Iotla kaolin from North Carolina. Their chemical analyses are as follows:

	GEORGIA KAOLIN	FLORIDA KAOLIN	NORTH CAROLINA KAOLIN
Moisture loss 105° C.	0.38	1.50	3.35
Loss on ignition	13.63	14.86	15.64
SiO_2	44.25	45.67	45.17
Al_2O_3	38.06	38.45	37.35
Fe_2O_3	1.03	0.75	0.60
TiO_2	1.29	0.10	0.03
CaO	0.08	....	trace
MgO	trace	0.05	trace
Na_2O	0.10	....	....
K_2O	0.70	0.06	0.70
Sulphur	0.06	....	....
Total	99.58	99.94	100.39

Description of Work. To study the effect of neutralizing a slip with sulphuric acid, a clay slip containing 20 percent clay and 80 percent water was used. After passing the clay through a 120 mesh sieve it was dried, crushed and again dried at 110° C. for 48 hours previous to testing the same. The kaolin was first treated with varying amounts of sodium hydroxide until maximum deflocculation was reached, and then a number of members, which had been treated with sodium hydroxide sufficient to produce maximum deflocculation, were neutralized by adding sulphuric acid. To study the changes in viscosity, measurements were made with a viscosimeter similar to that used by Bleininger.[8] The kaolin in the different members was then filtered from the original water which contained some soluble salts and new slips were prepared with fresh distilled water, and viscosity measurements were made with these slips.

In order to study the effect of alkalies on the viscosity of kaolins treated with different amounts of sulphuric acid the kaolin was first deflocculated with sodium hydroxide, neutralized with different amounts of sulphuric acid and filtered. The clay samples, thus treated, were then deflocculated with varying amounts of sodium hydroxide and viscosity measurements were made.

In measuring the viscosity the time necessary for 250 cc. of slip to pass through an orifice $^3/_{32}$ inch was measured with a stop watch. The time necessary for the same amount of water at 18° C. was then measured. The densities of the slip and water were determined, and by means of the following equation the relative viscosities x were calculated.

$$X = \frac{dt}{dw\ tw}$$

In this equation which is used for calculating relative viscosities for liquids with the Ostwald viscosimeter[9] d and d_w are the densities of the liquid and water respectively, and t and t_w are the times required for the discharge of equal volumes of

[8] Bleininger, A. V., Notes on Casting: *Trans. Amer. Cer. Soc., XVII*, 1915, p. 331.

[9] Senter, G., *Outlines of Physical Chemistry*, London, D. Van Nostrand Co., 1916, p. 75.

liquid and water respectively. Owing to the fact that a clay slip is not an ideal liquid and to the difference in construction of the viscosimeters this equation is not exactly correct, but for this investigation it is sufficiently accurate.

The degree of sedimentation was studied by putting the freshly treated slips in tall glass tubes and at the end of 24 and 72 hours respectively the height of the kaolin was measured and expressed in terms of the total heights of the slip as the percent height of clay in the slip.

One inch cubes were molded with 50 parts of filtered kaolin and 50 parts of potters flint, and after the cubes had dried in air their color was observed. In some cases cubes were made with all kaolin, and their color was also observed when dry.

The cubes containing 50 percent flint were finally dried at 110° C., and the time necessary for them to disintegrate in water at room temperatures was measured.

RESULTS OF WORK

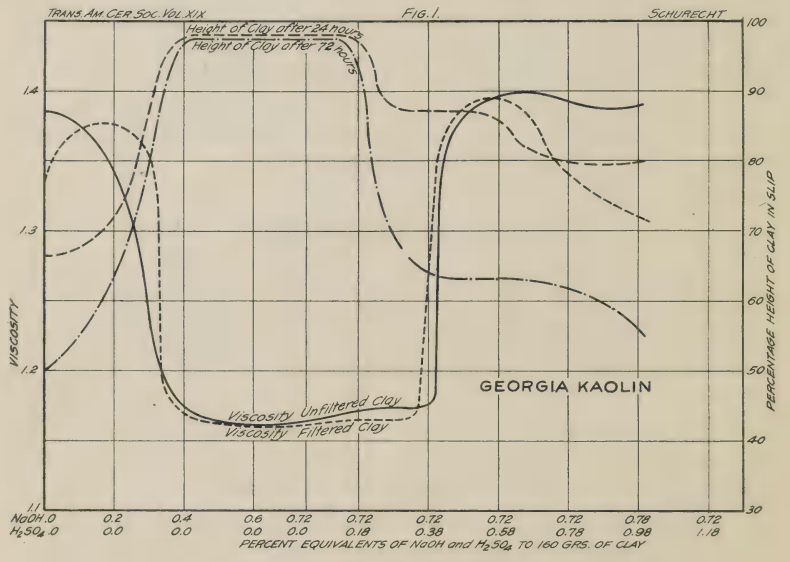
Georgia Kaolin. It was found that Georgia kaolin reached a state of maximum deflocculation when 0.72 percent of one equivalent (*i. e.*, 0.288 grams) of sodium hydroxide was added to the slip containing 160 grams of clay and 640 grams of water.

By examining the viscosity curve of the unfiltered clay, Figure 1, we see that upon neutralizing the sodium hydroxide with sulphuric acid the increase in viscosity is at first very slight until 0.38 percent equivalent of acid are added when there is a sudden rise in viscosity from 1.174 to 1.370. The viscosity curve of the filtered clay appears to be close to that of the unfiltered clay except where an excess of sulphuric acid has been added, and here the viscosity appears to be lower than that of the unfiltered clay. It was found that the fine deflocculated clay passed through even the finest filter paper to a small extent.

Upon examining the curve representing the percent height of kaolin after 24 hours, it appears that the untreated kaolin settled 34 percent while the kaolin which had been treated with 0.72 percent equivalent of sodium hydroxide and an equivalent amount of sulphuric acid settled only 20 percent.

After allowing the slip to stand 72 hours the untreated kaolin settled 50 percent while the slip neutralized with an equivalent amount of sulphuric acid settled 37.2 per cent. It appears from this, that after this kaolin has been treated with alkalies and sulphuric acid it is necessary to allow the slip to settle for a much longer time than was necessary before it was so treated.

The cubes made with 50 percent kaolin and 50 percent flint were allowed to dry in air for 5 days. Cubes made with the


TRANS. AM. CER. SOC. VOL. XIX
FIG. 1.
SCHURECHT
Height of Clay after 24 hours
Height of Clay after 72 hours
GEORGIA KAOLIN
Viscosity Unfiltered Clay
Viscosity Filtered Clay
VISCOSITY
PERCENTAGE HEIGHT OF CLAY IN SLIP
PERCENT EQUIVALENTS OF NaOH and H_2SO_4 TO 160 GRS. OF CLAY
NaOH 0 0.2 0.4 0.6 0.72 0.72 0.72 0.72 0.72 0.78 0.72
H_2SO_4 0 0.0 0.0 0.0 0.0 0.18 0.38 0.58 0.78 0.98 1.18

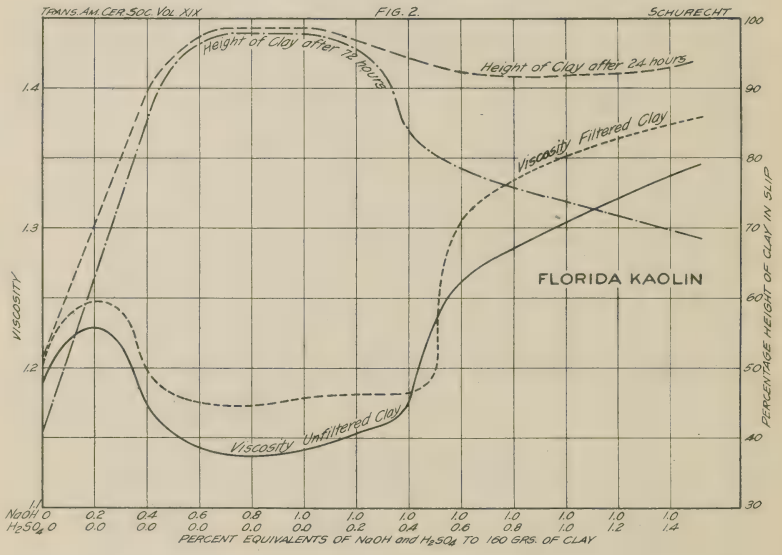
deflocculated kaolin appeared to be whiter than the untreated kaolin and very fine grained. Upon adding sulphuric acid the color remains white until an amount of sulphuric acid equivalent to the sodium hydroxide originally used is added, when the color becomes a slightly bluish gray. Upon adding more sulphuric acid the color becomes decidedly darker. The dark discoloration was not so pronounced in the cubes of all clay as it was in the cubes containing 50 percent flint, showing that the fast drying due to the open structure of this body increased the discoloration. In this case it appears that the discoloration

TABLE I. GEORGIA KAOLIN WITH SODIUM HYDROXIDE AND SULPHURIC ACID

NO.	NaOH IN TERMS OF DRY CLAY	H_2SO_4 IN TERMS OF DRY CLAY	EQUIVALENTS OF NaOH	EQUIVALENTS OF H_2SO_4	VISCOSITY OF UNFILTERED CLAY	VISCOSITY OF FILTERED CLAY	TIME OF DISINTEGRATION, MINUTES	HEIGHT OF CLAY, 24 HRS.	HEIGHT OF CLAY, 72 HRS.	APPEARANCE OF WATER ABOVE CLAY	COLOR OF DRY FILTERED CLAY
	percent	*percent*	*percent*	*percent*				*percent*	*percent*		
1	0.00	0.000	0.00	0.00	1.391	1.335	5.5	66.0	50.0	Clear	White
2	0.06	0.000	0.24	0.00	1.323	1.375	.....	76.0	69.0	Clear	White
3	0.08	0.000	0.32	0.00	1.198	1.320	110.0	98.0	97.5	Turbid	White
4	0.10	0.000	0.40	0.00	1.175	1.169	115.0	98.0	97.5	Turbid	White
5	0.12	0.000	0.48	0.00	1.163	1.163	106.0	98.0	97.5	Turbid	White
6	0.18	0.000	0.72	0.00	1.163	1.163	110.0	98.0	97.5	Turbid	White
7	0.18	0.056	0.72	0.18	1.173	1.163	82.0	97.8	97.5	Turbid	White
8	0.18	0.111	0.72	0.36	1.200	1.250	31.0	86.8	68.5	Turbid	White
9	0.18	0.166	0.72	0.54	1.395	1.395	5.8	88.0	63.3	Clear	White
10	0.18	0.221	0.72	0.72	1.395	1.355	5.8	80.0	62.8	Clear	Faint gray
11	0.18	0.307	0.72	1.00	1.390	1.310	5.3	80.0	56.2	Clear	Gray

is due to adding too much sulphuric acid, an amount less than the equivalent of sodium hydroxide giving the best white color.

The time of disintegration in water of the untreated kaolin is 5.5 minutes while the time of disintegration of the deflocculated kaolin is 110 minutes. Since clays which disintegrate slowly often have a high tensile strength, this seems to be in accordance with Bleininger's observations[10] in which


TRANS. AM. CER. SOC. VOL. XIX
FIG. 2.
SCHURECHT
Height of Clay after 12 hours
Height of Clay after 24 hours
Viscosity Filtered Clay
Viscosity Unfiltered Clay
FLORIDA KAOLIN
VISCOSITY
PERCENTAGE HEIGHT OF CLAY IN SLIP
PERCENT EQUIVALENTS OF NaOH and H2SO4 TO 160 GRS. OF CLAY

he found that cast bodies containing alkalies may have a higher tensile strength than those cast without these reagents. When neutralized with an equivalent amount of sulphuric acid the time of disintegration is reduced to 5.8 minutes.

Florida Kaolin. It was found that Florida kaolin reached the state of maximum deflocculation when 1.0 percent of one equivalent of sodium hydroxide was added to a slip containing 160 parts of kaolin and 640 parts of water.

It is interesting to note that with small additions of sodium hydroxide (see Figure 2), the viscosity of the slip increases,

[10] Bleininger, A. V., Use of Sodium Salts in the Purification of Clays and in the Casting Process: *Bureau of Standards Tech. Paper 51*, p. 40.

TABLE II. FLORIDA KAOLIN WITH SODIUM HYDROXIDE AND SULPHURIC ACID

NO.	NaOH IN TERMS OF DRY CLAY	H_2SO_4 IN TERMS OF DRY CLAY	EQUIVALENTS OF NaOH	EQUIVALENTS OF H_2SO_4	VISCOSITY OF UNFILTERED CLAY	VISCOSITY OF FILTERED CLAY	TIME OF DISINTEGRATION, MINUTES	HEIGHT OF CLAY, 24 HRS.	HEIGHT OF CLAY, 72 HRS.	APPEARANCE OF WATER ABOVE CLAY	COLOR OF DRY FILTERED CLAY
	percent	*percent*	*percent*	*percent*				*percent*	*percent*		
1	0.00	0.000	0.00	0.00	1.187	1.201	4.8	51.5	41.3	Clear	White
2	0.05	0.000	0.20	0.00	1.230	1.248	6.1	70.5	63.5	Clear	White
3	0.10	0.000	0.40	0.00	1.170	1.200	10.3	90.0	86.0	Turbid	White
4	0.15	0.000	0.60	0.00	1.140	1.175	19.2	97.5	97.0	Turbid	White
5	0.20	0.000	0.80	0.00	1.140	1.173	32.8	98.5	98.0	Turbid	White
6	0.25	0.000	1.00	0.00	1.139	1.180	31.7	98.5	98.0	Turbid	White
7	0.25	0.077	1.00	0.25	1.158	1.180	21.0	96.0	95.0	Turbid	White
8	0.25	0.154	1.00	0.50	1.238	1.196	10.0	93.4	80.0	Turbid	White
9	0.25	0.231	1.00	0.75	1.283	1.328	8.0	91.6	79.3	Slightly turbid	White
10	0.25	0.307	1.00	1.00	1.306	1.358	6.1	91.6	73.6	Clear	White
11	0.25	0.460	1.00	1.50	1.345	1.380	5.5	94.8	68.7	Clear	White

and then with larger additions it decreases. This increase may be due to the presence of soluble calcium[11] which is converted into calcium hydroxide when sodium hydroxide is added. Upon adding sulphuric acid it is seen that the increase in viscosity is at first small until between 0.25 and 0.50 percents of one equivalent of acid are added when the viscosity suddenly rises from 1.158 to 1.238. When sulphuric acid equivalent to the sodium hydroxide is added the viscosity becomes 1.306 which is much higher than it was for the untreated clay. The increase in plasticity, which in some cases caused kaolin refiners trouble is undoubtedly due to this increase in viscosity. This can be reduced by adding less sulphuric acid. For instance the viscosity 1.187, which is the viscosity of the untreated clay, is reached when 0.42 percent of one equivalent of sulphuric acid is added. The viscosities of the filtered kaolin appear higher than those of the unfiltered clay.

Examining the curve representing the height of kaolin in the slip after 24 hours we find that the clay has settled only 8.4 percent after the chemical treatment, while in the same slip before it was treated the kaolin settled 48.5 percent. After 72 hours the untreated kaolin settled 58.7 percent while the slip neutralized with an equivalent amount of sulphuric acid settled 26.4 percent. In this case again it will be necessary to allow the chemically treated slip to settle for a longer time than was necessary for the untreated slip. Whether some other reagent will act better than sulphuric acid in this respect remains to be seen.

The kaolin treated with an excess of sulphuric acid in this case showed no black discoloration showing that some clays are not discolored by adding a slight excess of acid.

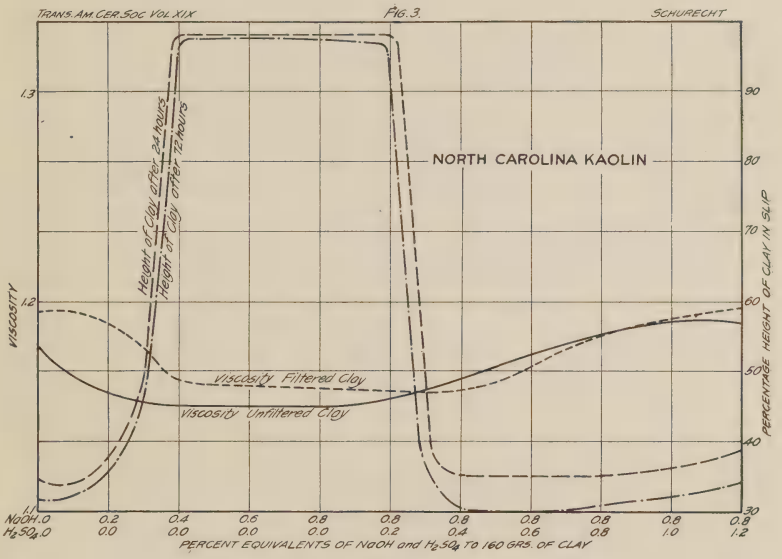
The time of disintegration in water of the untreated kaolin is 4.8 minutes, while for the deflocculated kaolin it is 31.7 minutes. Upon neutralizing the sodium hydroxide with acid the time becomes 6.1 minutes.

[11] Förster, F., Ueber das Gieszen des Tones: *Chem. Industrie*, 28, 1905, pp. 733–740.

North Carolina Kaolin. North Carolina kaolin was deflocculated with 0.8 percent of one equivalent of sodium hydroxide added to a slip containing 160 grams of clay and 640 grams of water.

The viscosity of the slip is 1.180 before it is treated, and when an equivalent amount of acid is added it becomes 1.186. The filtered clay has a viscosity slightly higher than the unfiltered clay.

The curve representing the height of clay in the slip shows that the settle after an equivalent amount of acid is added is


TRANS. AM. CER. SOC. VOL. XIX
FIG. 3.
SCHURECHT
NORTH CAROLINA KAOLIN
Height of Clay after 24 hours
Height of Clay after 2 hours
Viscosity Filtered Clay
Viscosity Unfiltered Clay
VISCOSITY
PERCENTAGE HEIGHT OF CLAY IN SLIP
PERCENT EQUIVALENTS OF NaOH and H_2SO_4 TO 160 GRS. OF CLAY

about the same as for the untreated kaolin. Twenty-four hours is amply sufficient to settle this kaolin.

The untreated clay showed a dark color upon drying. This color became less apparent when the kaolin was deflocculated, but when an amount of acid equivalent to or more than equivalent to the sodium hydroxide is added the black scumming appears worse than on the untreated kaolin.

The time of disintegration in water for the deflocculated kaolin was again greater than that of the untreated kaolin.

TABLE III. NORTH CAROLINA KAOLIN WITH SODIUM HYDROXIDE AND SULPHURIC ACID

NO.	NaOH IN TERMS OF DRY CLAY	H_2SO_4 IN TERMS OF DRY CLAY	EQUIVALENTS OF NaOH	EQUIVALENTS OF H_2SO_4	VISCOSITY OF UNFILTERED CLAY	VISCOSITY OF FILTERED CLAY	TIME OF DISINTEGRATION, MINUTES	HEIGHT OF CLAY, 24 HRS.	HEIGHT OF CLAY, 72 HRS.	APPEARANCE OF WATER ABOVE CLAY	COLOR OF DRY FILTERED CLAY
	percent	*percent*	*percent*	*percent*				*percent*	*percent*		
1	0.00	0.000	0.00	0.00	1.180	1.195	5.8	34.4	32.7	Clear	Light gray
2	0.05	0.000	0.20	0.00	1.154	1.190	7.7	35.9	32.0	Turbid	Light gray
3	0.10	0.000	0.40	0.00	1.150	1.163	8.2	98.0	97.0	Turbid	Light gray
4	0.15	0.000	0.60	0.00	1.151	1.161	11.2	98.0	97.0	Turbid	Light gray
5	0.20	0.000	0.80	0.00	1.151	1.157	16.4	98.0	97.0	Turbid	Faint gray
6	0.20	0.062	0.80	0.20	1.153	1.157	11.0	97.8	96.0	Turbid	Light gray
7	0.20	0.123	0.80	0.40	1.168	1.157	8.9	35.0	30.0	Turbid	Light gray
8	0.20	0.184	0.80	0.60	1.175	1.169	7.5	35.2	30.0	Clear	Light gray
9	0.20	0.246	0.80	0.80	1.186	1.183	6.5	36.0	32.4	Clear	Gray
10	0.20	0.385	0.80	1.25	1.192	1.200	4.6	37.2	33.8	Clear	Gray

Treatment With Different Amounts of Sulphuric Acid. Georgia kaolin was treated with 0.72 percent of one equivalent of sodium hydroxide, which was added to a slip containing 160 grams of clay and 640 grams of water. See Table IV. Different members were then treated with 0.52, 0.72 and 1.00 percents of one equivalent of sulphuric acid respectively. The clay was then filtered, and varying amounts of sodium hydroxide were added. Where the larger quantities of sulphuric acid have been used larger quantities of sodium hydroxide are necessary to produce minimum viscosity in the slip. Where an excess of sulphuric acid has been used the viscosity of the kaolin first increases, and then when more sodium hydroxide is added the viscosity again decreases to a minimum. The difference in behavior of the kaolin treated with different amounts of sulphuric acid is most pronounced when small additions of alkali are added and is not very great where larger amounts of alkalies are added.

TABLE IV. VISCOSITIES OF GEORGIA KAOLIN WITH DIFFERENT AMOUNTS OF SULPHURIC ACID

NO.	NaOH IN TERMS OF DRY CLAY	UNTREATED	TREATED WITH 0.72 PER CENT EQUIV. NaOH		
			WITH 0.54 PER CENT EQUIV. H_2SO_4	WITH 0.72 PERCENT EQUIV. H_2SO_4	WITH 1.00 PERCENT EQUIV. H_2SO_4
	percent				
1	0.000	1.390	1.387	1.322	1.323
2	0.096	1.180	1.248	1.270	1.420
3	0.128	1.165	1.142	1.165	1.442
4	0.160	1.163	1.143	1.147	1.332
5	0.192	1.163	1.142	1.147	1.158
6	0.288	1.168	1.142	1.144	1.150
7	0.384	1.168	1.145	1.147	1.155
8	0.480	1.168	1.155	1.336	1.164
9	0.800	1.168	1.162	1.332	1.164

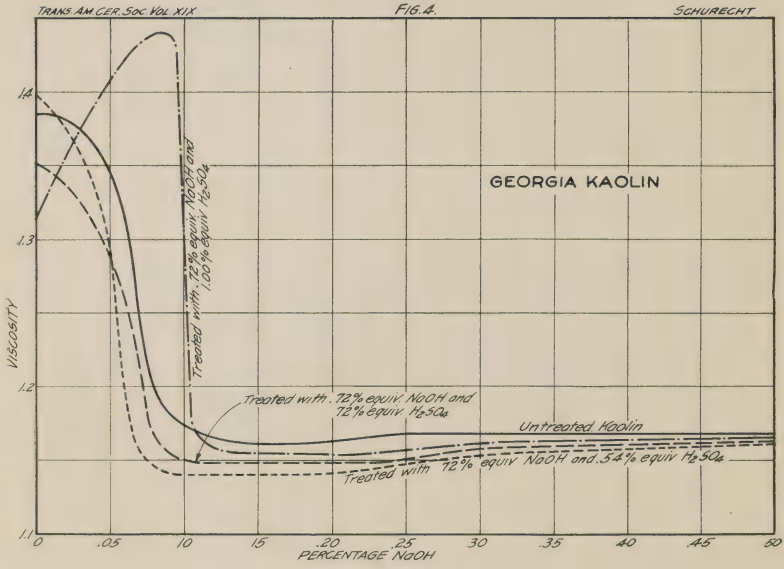
SUMMARY

The viscosity data indicates that in the case of Florida and North Carolina kaolins the viscosity is increased over what it was originally when the slip is neutralized with sulphuric acid equivalent to the sodium hydroxide first added. To re-

duce this, an amount of sulphuric acid less than the equivalent of sodium hydroxide should be added, this amount varying with different clays.

In the case of the Florida and Georgia kaolins, it was found that the sedimentation was much slower after the slips had been treated with sodium hydroxide and sulphuric acid than before they were treated.

In some cases the black discoloration on the dry kaolin is caused by adding an excess of sulphuric acid. The proper



amount to use to overcome this would have to be determined for each clay. It seems that an amount less than the equivalent amount of sodium hydroxide is satisfactory in most cases.

The deflocculated kaolin in each case could not be filtered, the fine particles passing through the filter to a small extent, and also clogging up the same. When the kaolin is partly neutralized by adding sulphuric acid to the slip it can be filtered readily.

The rate of disintegration in water is much slower for the deflocculated kaolin than for the untreated kaolin.

Care should be taken to add the same amount of acid to alkali in the kaolin slip, because any variation of acid would make the kaolin act differently towards alkalies. Those slips which have been treated with larger additions of sulphuric acid require more alkalies to produce the same degree of dispersion.

In conclusion the author wishes to acknowledge his indebtedness to Prof. A. S. Watts for suggestions on this work.

DISCUSSION

Mr. Washburn: One might suspect that the presence of the black material might be due to the charring of the organic matter either in the water or the clay, and that could be easily ascertained by seeing if the same effect is produced when hydrochloric acid is employed.

Mr. Barringer: Has any other acid been used in experimenting?

Mr. Schurecht: No other acid was used in experimenting, because we did not have time. I might say that we concentrated some of the liquid which we filtered off of the clay and made another briquette out of it, and we found that the scumming effect was much more pronounced than it was originally. This would tend to show that it is the effect of sulphuric acid on the organic matter that causes this trouble. The vapor tension of sulphuric acid is much less than that of water, and therefore during the last stages of drying the concentration of the sulphuric acid is high.

ENAMEL SURFACES UNDER THE MICROSCOPE

BY EMERSON P. POSTE

In connection with papers on "The Relative Action of Acids on Enamel" contained in Volume XVII, page 137 and Volume XVIII, pages 162 and 927 of the Transactions of this Society, it was brought out that while proper acid resistance of a frit is a prerequisite for the quality of the final product, other matters have a bearing on the resistance of the enamel as it meets the trade.

There are two possible changes caused by subsequent manipulation which could alter the resistance of the frit. Variations in the processes might bring about, in the first place, physical differences as to the final surface and homogeneity of the enamel, and secondly, chemical changes either by virtue of mill additions or further reaction due to the burning of the ware.

A thorough investigation of the above ideas would include a study of the physical and chemical conditions of the enamel as it exists after burning. Some efforts have been made along this line involving a study of enamel surfaces under the microscope. It may be worth while to note the results.

Procedure. The work which has been done to date involves a brief study of the variations of physical condition of the enamel after burning and the bearing of these differences on the acid resistance of the enamel, together with an examination of various commercial enamels from a point of view of their physical homogeneity as revealed by the microscope.

A relatively soft enamel which is in commercial use was employed in making a series of trial cups, which were burned under varying conditions. The first piece, designated as A-1, was underburned but to a degree which would not carry it far beyond a commercial possibility. The second, A-2, was given as near the proper burn as possible and the third, A-3, was somewhat overburned. The resulting pieces were examined under the microscope. Three similar cups designated as A-4, A-5

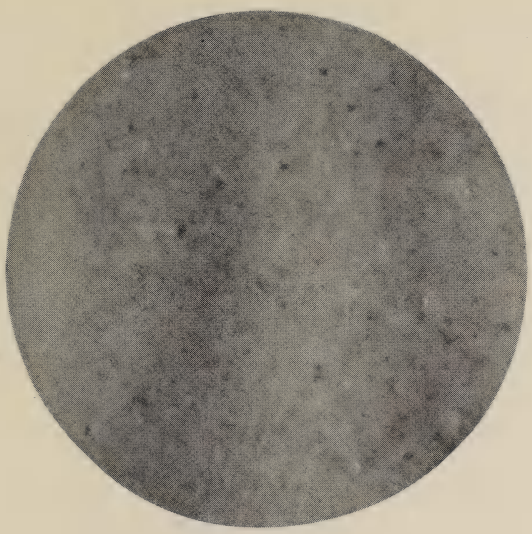


FIG. 1. Sample A 1.

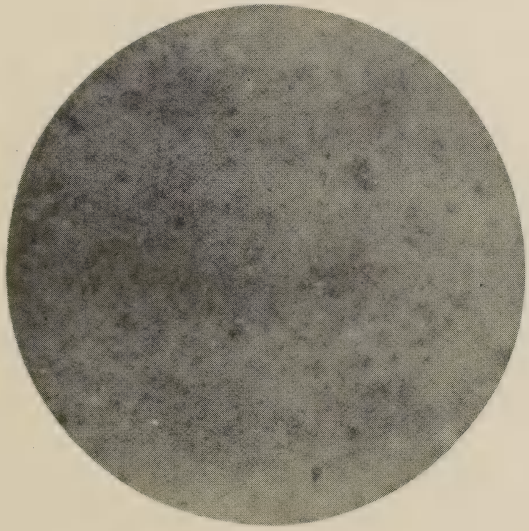


FIG. 2. Sample A 2.

and A-6, were burned under the same conditions as A-1, A-2 and A-3, respectively, and treated with warm dilute hydrochloric acid for several hours. The resulting surfaces were examined and photographed.

The second portion of the work involved obtaining various specimens of commercial enamels from both the culinary and the acid resisting field. The samples examined were the following:

B-1 A sample of gray ware branded "Extra Coated..... Aluminum" — apparently a two-coat enamel.

B-2 A one-coat granite.

B-3 A mottled chocolate-brown and white, branded "Triple Coated.....".

B-4 A mottled blue and white.

B-5 A pale blue German enamel.

B-6 A blue acid-resisting ware of inferior quality.

B-7 A mottled brown acid-resisting enamel.

B-8 A blue acid-resisting enamel.

Several samples of white ware were examined, but no satisfactory results as to microphotographs were obtained due to a lack of contrast of the field.

The microscopic examination has involved a study of the surface of the enamel as it has appeared with oblique illumination and a magnification of about 75 diameters at the plate of the camera. The use of larger magnifications has failed to give as comprehensive an idea of the general conditions as has the above mentioned power. To determine the nature of certain areas which appeared indefinite at 75 diameters, higher powers have been used. The result has been the identification of various small collections of minute bubbles, which at 75 diameters suggested unfused material.

Observations. Parallel to the consideration of the microphotographs, it will be well to describe briefly each sample as it appears to the naked eye.

Sample A-1: A medium blue enamel with fair gloss, the surface being slightly rough to the touch. Under the microscope

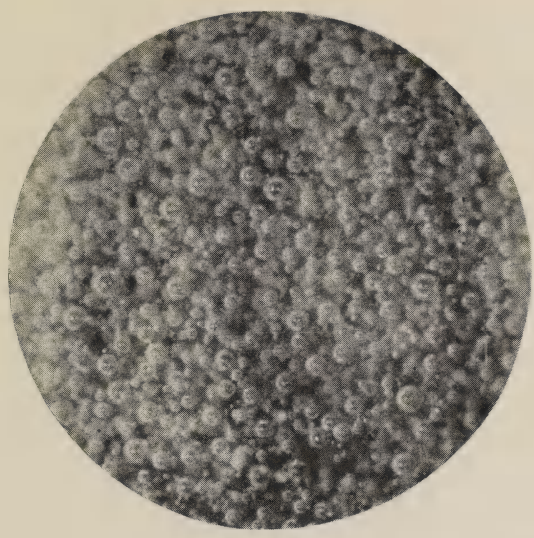


FIG. 3. Sample A 3.

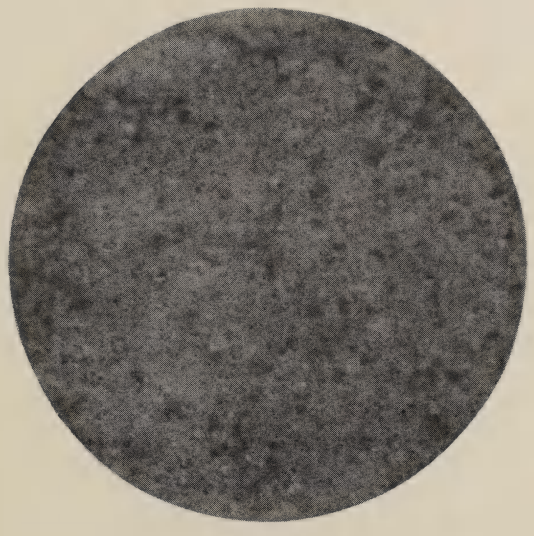


FIG. 4. Sample A 4.

this enamel shows an indefinite field of unfused material and minute bubbles with practically no large bubbles. Fig. 1.

Sample A-2: The enamel is about the same in color as A-1, but has a much better gloss and is smooth to the touch. There is no surface pitting. The microphotograph shows a reasonably uniform field similar to that obtained from A-1 and in addition a noticeable distribution of large bubbles on a background containing unfused material and fine bubbles. Fig. 2.

Sample A-3: The color of the enamel is much darker than A-1 and A-2. The gloss is very good, but there is a tendency to surface pitting. On magnification there is found to be a dark blue background of homogeneous glass showing no unfused material. In the foreground is a very even distribution of large well formed bubbles. Fig. 3.

Before discussing samples A-4, A-5, and A-6, it will be necessary to understand the difference of surface appearance of a blue enamel produced by different degrees or acid action. If the action is very slight a peculiar surface discoloration without appreciable loss of gloss is noted. As the action becomes more severe, the discoloration develops to a loss of gloss and a lighter color. The surface can be definitely scratched with a knife. As the action again increases, the more soluble constituents of the enamel go into solution, and leave behind a very fine, white powder which can be rubbed off when the surface is dry. This condition is termed "chalking" and indicates a very severe action. With these points in mind we can more clearly discuss the samples which have been tested with acid.

Sample A-4: Similar to A-1, treated with acid. Surface dull and light in color. Practically no chalking. Under the microscope quite similar to A-1. The tops of some of the small bubbles are apparently eaten off, leaving minute crater-like spots. Fig. 4.

Sample A-5: To the naked eye this sample is very similar to A-4. Fine hair-like lines show traces of "curling" which should not be taken as bearing on the present consideration. This sample showed practically no chalking. Under the

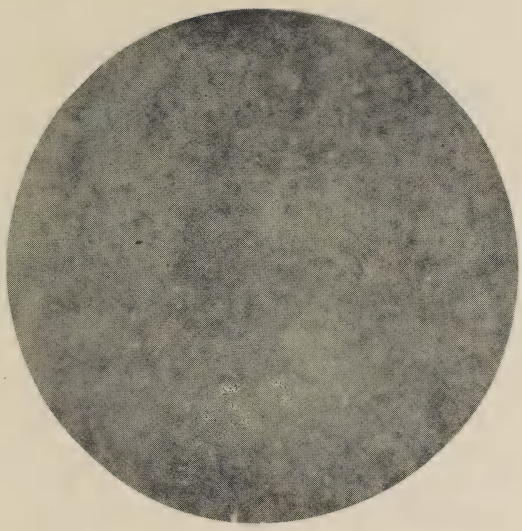


FIG. 5. Sample A 5.

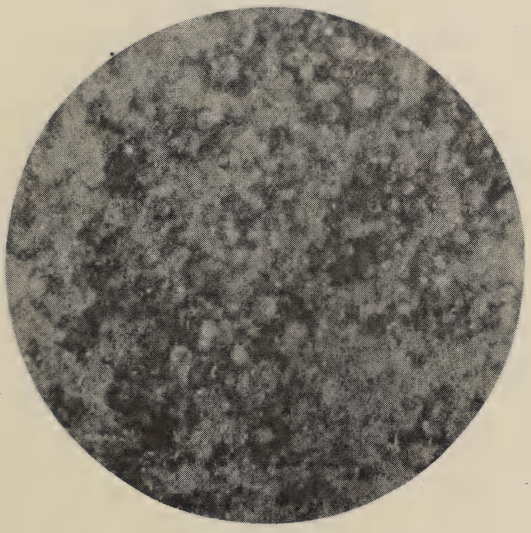


FIG. 6. Sample A 6.

microscope the appearance is quite similar to that of A-4 only the minute craters are slightly more noticeable. Fig. 5.

Sample A-6: The appearance of this sample after the acid treatment was quite similar to A-5 and A-4, except that surface was lighter in color. It has chalked very markedly, showing a far greater action by the acid than was the case with either of the other samples. The microscope shows that many of the larger bubbles indicated in the microphotograph of A-3 have been destroyed, leaving cup shaped depressions scattered over the surface. Several of the bubbles which apparently were not reached by the acid can be seen in the background. Fig. 6.

Commercial Ware. Keeping the foregoing observations in mind and remembering that A-1 and A-4 were underburned, A-2 and A-5 normally burned and A-3 and A-6 overburned, it will be interesting to consider in like manner the various samples of commercial ware and the microphotographs obtained therefrom.

Sample B-1: This is a light gray, fairly glossy enamel with a few dark gray blotches, the surface in general being quite spotted and pitted. The microscope shows a field consisting essentially of minute bubbles in the background with larger ones near the surface. There are a few blotches of a very indefinite nature. As a whole the porosity is quite marked. The microphotograph is very unsatisfactory, in view of the uniformity of color and resulting lack of contrast, although the specimen observed under the microscope with the eye shows the above very definite characteristics.

Sample B-2: This is a glossy granite with the light and dark portions quite evenly distributed. Some surface spotting and pitting is noticeable. The microscope discloses a field of light and dark gray, quite porous, the lighter portion consisting of finer bubbles than the dark portion. There is a trace of unfused material scattered throughout the field. The porosity as a whole is quite marked and irregular.

Sample B-3: This enamel is a very pleasing, glossy, chocolate-brown and white mottled product with a good sur-

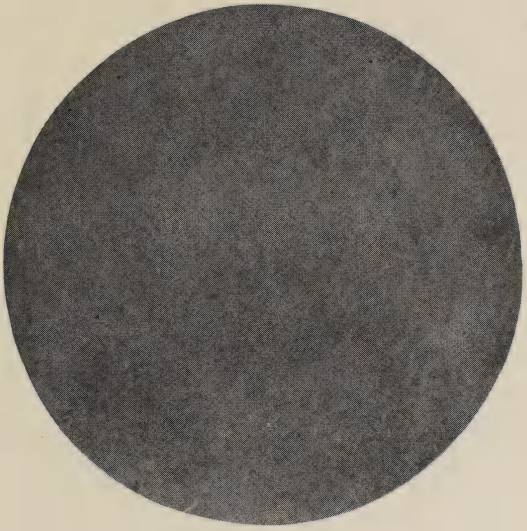


FIG. 7. Sample B 1.

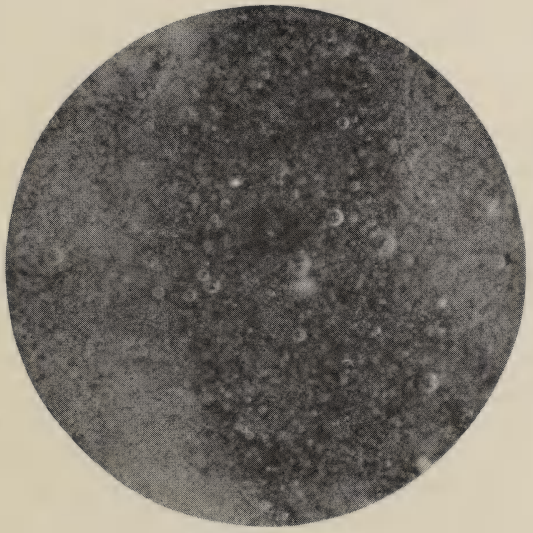


FIG. 8. Sample B 2.

face. Under the microscope are seen white blotches intermixed with chocolate-brown blotches, both consisting of bubbles fairly uniform in size and quite close together.

Sample B-4: This enamel is blue with a few white blotches and has rather poor gloss. There is practically no pitting on the surface. The microscopic field is very indefinite, consisting of rather irregular dark blue areas between patches of lighter blue porous material. The average bubble size is apparently much smaller than in the previous samples observed.

Sample B-5: This is a light blue enamel with a very good gloss and pleasing appearance. There is apparently no pitting, but on close examination an irregular surface spotting is noted. With the microscope one notes an indefinite field consisting of a light blue background containing fine bubbles and unfused material, through which are scattered rather large bubbles and particles of dark blue material together with blotches suggesting dirt fused on to the surface of the enamel.

Sample B-6: This enamel is a glossy dark blue with some surface pitting. It resembles a thick somewhat overburned ground coat. The microscopic field shows an indefinite blue background with numerous large, well developed, spherical bubbles in the foreground. There is no indication of unfused material.

Sample B-7: This is a mottled enamel of dark and lighter brown color, with a glossy surface. There is practically no pitting. The microscope shows a mass of irregular bubbles with particles of unfused material near the surface and rather indefinite blotches some of which seem to be surface scars.

Sample B-8: This enamel is medium blue in color with good gloss and practically no surface pitting. Under the microscope it presents a very uniform field consisting essentially of minute bubbles.

Conclusions. The foregoing considerations show quite definitely that a marked difference in physical condition may be brought about by variations in treatment of a given frit and that under commercial conditions such variations do exist. If the enamel is rather lightly burned, the major portion seems to

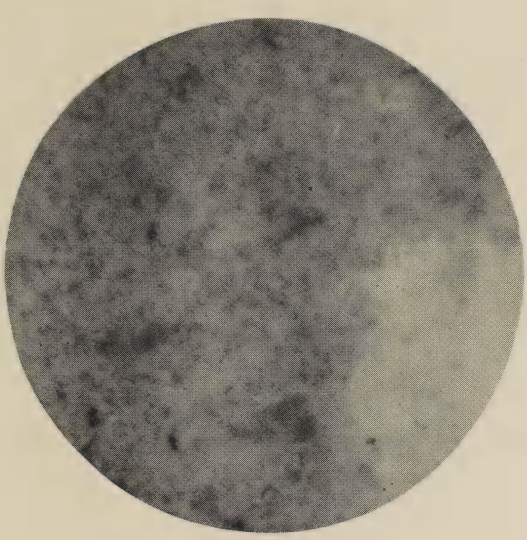


FIG. 9. Sample B 3.

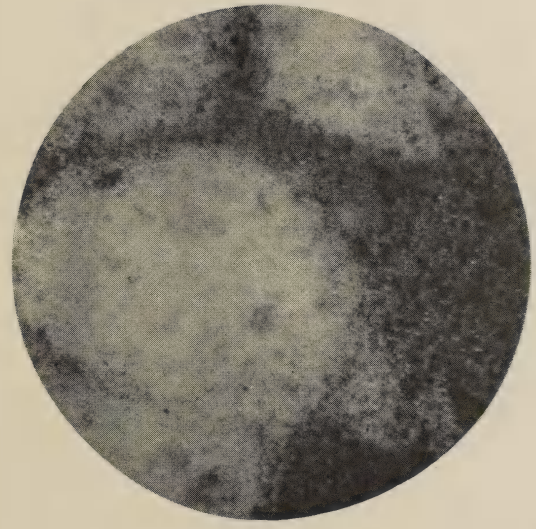


FIG. 10. Sample B 4.

fuse to a matrix of glass containing fine bubbles and particles of unfused material in suspension. No doubt this unfused material consists essentially of clay or other of the more refractory mill additions. If the enamel is burned to about the normal degree, this unfused material practically disappears and the minute bubbles seem to run together, forming larger units and leaving greater masses of glassy material between. On further burning, the bubbles continue to combine until they become of sufficient size to produce surface pitting which can be detected by the naked eye. There are apparently chemical reactions which take place, resulting in the formation of gases giving rise to this increasing porosity.

The writer wishes to express his appreciation for the valuable co-operation of his assistant, Mr. S. F. Pickering, in obtaining the above microphotographs.

DISCUSSION

Mr. Shaw: I wish to say just one word, in regard to the formation of those bubbles; in re-burning it seems reasonable to suppose that when you put raw clay, borax and magnesium sulphate in your enamel that you are going to have some reaction when you heat it to a thousand degrees. I think that insufficient smelting is probably the cause of a good deal of the action which takes place after the enamel is put on the ware.

DISCUSSION SUBMITTED AFTER READING PAPER

Mr. Shaw: I think Mr. Poste has performed a distinct service in revealing the exact physical nature of enamels.

The general conception of an iron enamel is that of a glass coating over the surface of the iron. In fact that is generally the description given; but a metal enamel when applied very rarely even approaches in its physical nature that of glass or glazes. The latter are as a rule homogeneous and free from gas bubbles while enamels are composed of small particles of enamel frit, melted and sintered together and containing innumerable bubbles of entrapped gases. This gas is partly air, partly

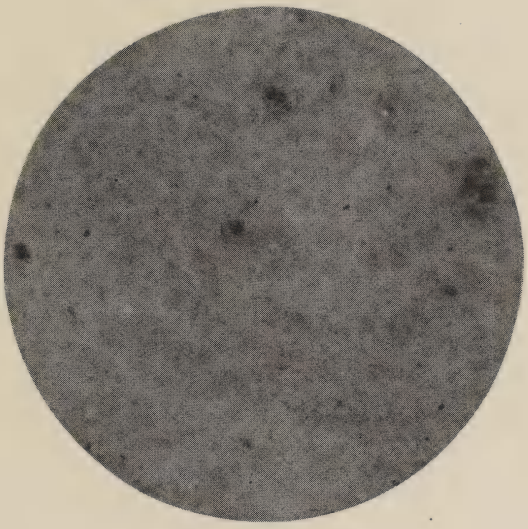


FIG. 11. Sample B 5.

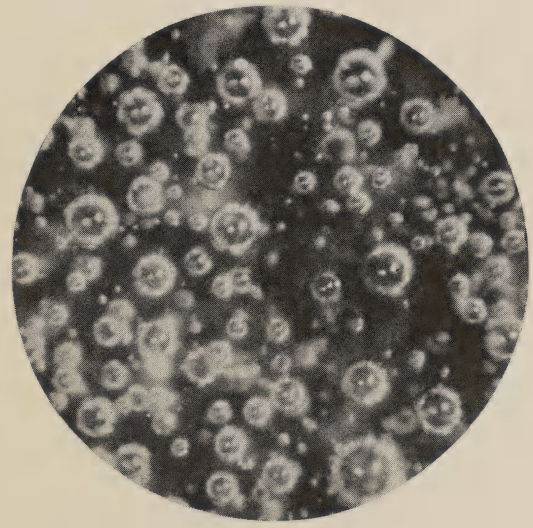


FIG. 12. Sample B 6.

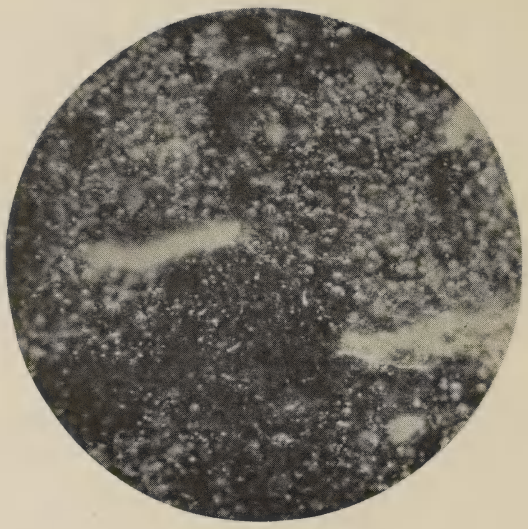


FIG. 13. Sample B 7.

FIG. 14. Sample B 8.

gases liberated from raw material added to the frit and partly gas liberated from the frit itself.

The method of applying enamels and the nature of the material to which they are applied preclude the possibility of burning them to such a state of homogeniety as is obtained in glass or glazes, but it is obvious that the more nearly they are brought to such a state the better they will be able to resist the corrosive action of solvents. In view of this fact the importance of the work outlined here by Mr. Poste becomes apparent and it is to be hoped he will carry it further.

GLASS SANDS

BY CHARLES R. FETTKE, PITTSBURG, PA.

Glass sands are sands that are made up almost entirely of quartz grains found in nature either in the form of loose, unconsolidated sediments or in deposits in which the individual grains are more or less thoroughly bound together by some cementing agent. In the manufacture of glass, such sands are now used almost exclusively as the source of the silica which is the major constituent of this useful substance.

Quartz crystallizes in the rhombohedral division of the hexagonal system. When the crystal form develops it most frequently consists of a hexagonal prism terminated by two rhombohedrons, or sometimes of double six-sided pyramids made up of two rhombohedrons. Usually it occurs in the massive form with no crystal faces developed. These occurrences vary from coarse to fine granular in texture, or even to cryptocrystalline as in the case of the chalcedonic and jaspery varieties. Quartz does not tend to break along any well defined planes, in other words it has no cleavage, but breaks with equal readiness in all directions. It usually breaks with a more or less rounded or curved surface known as conchoidal fracture. Its hardness is seven according to Moh's scale, which makes it a comparatively hard mineral. Its specific gravity varies from 2.653 to 2.654. In thin sections quartz is colorless, but it often contains inclusions of various kinds which serve as pigments and give a color to thick slices and masses of the mineral. Thus quartz may be yellow, red, brown, green, blue, or black. It has a vitreous luster.

Quartz according to Day and Shepherd fuses at a temperature of 1600° C or 2912° F. When finely ground quartz is heated with tungstate of soda it remains unchanged until a temperature of about 870° C. is reached. At temperatures above this, it is gradually converted into tridymite. Tridymite occurs in nature as a mineral in certain volcanic lavas, especially the

more siliceous and feldspathic kinds either in the form of small aggregations in the massive rock or as minute crystals in cavities associated with quartz or opal and feldspar. It has also been found in meteorites. Tridymite is stable at all temperatures from 870°±C. up to 1470°±C., where the inversion to a third form known as cristobalite takes place[1]. From 1470°C. on, no further changes occur up to the melting point.

Quartz is unattacked by acids other than hydrofluoric and is only slightly attacked by solutions of the fixed caustic alkalies. This resistance to the attack of the ordinary acids explains the general absence of alterations in the quartz crystals of rocks, except where they have been subjected to profound alteration or metamorphism. Ordinary processes of weathering do not attack quartz. It appears fresh and unaltered when other minerals have been decomposed.

Quartz, as has already been pointed out, very frequently contains inclusions of other substances. At times these are sufficiently large to be visible to the naked eye but usually they are of microscopic size. These inclusions are largely responsible for the various colors developed at times in quartz. They may be divided into gaseous, liquid, and solid inclusions.

The gaseous and liquid inclusions usually occupy irregularly shaped cavities in the quartz, although sometimes they have the form of the enclosing mineral. The liquid in most cases is water, but liquid carbon dioxide may also be present. Gaseous bubbles sometimes movable, often accompany the liquid inclusions. Cubes of some colorless mineral, possibly sodium chloride, are also found occasionally in these cavities. This causes the fetid odor of certain samples of quartz when struck a sharp blow. The milky white color developed in certain varieties of quartz is generally due to the reflection of light from these inclusions of gas and liquid.

Among the solid inclusions found in quartz are a considerable number of minerals. One of the most common of these is rutile (TiO_2), which often occurs in quartz in extremely thin microscopic needles. Minute crystals of apatite and plates of

[1] The Various Forms of Silica and Their Mutual Relations. Clarence Fenner. *Journal of the Washington Academy of Sciences*, December 4, 1912, Vol. 2.)

ilmenite abound in blue quartzes, found in certain granites and porphyries. Other minerals occasionally found in quartz as inclusions are needles of tourmaline, epidote, actinolite, tremolite, and chlorite. These are the most common mineral inclusions, but others have also been found in certain quartzes. These inclusions are often arranged along lines, curved surfaces, or sometimes parallel to the crystal faces of the quartz.

Quartz is one of the most abundant minerals found in nature. It is an essential constituent of many igneous rocks among the most important of which may be mentioned rhyolite, granite, dacite, quartz diorite, granite pegmatite, and the corresponding porphyries. In such sedimentary rocks as sandstone and conglomerate and the loose materials, sand and gravel from which these are derived, it is usually the chief and often nearly the only constituent present. In many of the metamorphic rocks such as the quartzites, gneisses, and the mica schists it is also an important component. It is also a very prominent vein forming mineral being often found occurring in fissures and other crevices and cavities in the rocks where it has been precipitated from silica bearing solutions. Considerable quantities are also deposited at times by hot springs and geysers. F. W. Clarke[2] estimated that quartz forms about 12 percent of the entire lithosphere.

From its widespread distribution in nature it will be readily seen that the mineral quartz must form under a great many different conditions. This is borne out by investigation. As has already been stated quartz is an important constituent of certain types of igneous rocks. Here it was crystallized directly from the molten condition. It is usually one of the last minerals to separate out where crystallization is taking place in a cooling lava or magma. Quartz occurring as a vein filling in fissures and other crevices in the earth's crust has crystallized out from water solutions. These solutions may have been at high temperatures at the time the crystallization occurred or they may have been at ordinary temperatures, the mineral being found in both types of veins. Quartz, therefore, forms in nature

[2] *Bulletin 616, U. S. Geol. Survey*, p. 361, 1916.)

either as a direct crystallization product from molten silicate solutions or by precipitation from water solutions.

As has been seen above, quartz occurs in nature in a large number of different forms and under a great variety of conditions. From the standpoint of the glass manufacturer, however, only a few of these are of interest as possible sources of silica for his purpose. At the present time very nearly pure quartz sands, made up almost entirely of little grains of quartz varying in size from 0.1 to 0.4 millimeters in diameter, furnish practically the only source of silica for the glass industry.

As has been stated before, quartz is an important constituent of many of the rocks which make up the lithosphere. Rocks are simply aggregates of one or more minerals. They can be divided into three large groups, namely, the igneous, the sedimentary, and the metamorphic. Igneous rocks are those which have been formed directly by consolidation from the molten state either underneath the earth's surface or upon it. Sedimentary rocks are those which have been formed by the accumulation and consolidation of materials derived from the mechanical disintegration and chemical decomposition of rocks of any one of the above types, upon exposure to the various agents of weathering active on the earth's surface. Metamorphic rocks are those which, originally either igneous or sedimentary, have been altered in texture, structure, or mineral composition through any one or more of the various geologic agents active in bringing about changes in rocks. Quartz is an essential constituent of certain rocks falling in all three of these groups. Among igneous rocks such types as rhyolite, granite, dacite and quartz diorite have already been mentioned, in the case of the sedimentary rocks, sandstones and conglomerates, and among metamorphic rocks, quartzites, mica schists, and gneisses.

For the purpose of glass manufacture, however, it is necessary that the quartz be not only an essential constituent of the rock, but it must be practically the only constituent present. This type of rock is found in the case of certain sandstones among the sedimentary rocks. Sand deposits and sandstones occur in nature that contain over 99 percent silica. It is, there-

fore, in the origin of this type of sedimentary rock that the glass manufacturer is particularly interested.

As has already been stated, sedimentary rocks are derived from materials produced by the mechanical disintegration and chemical decomposition of previously existing rocks on the earth's surface which have been exposed to the action of the various atmospheric agents such as the gases present in the atmosphere, rain, frost, and changes of temperature. The alteration which takes place when rocks are thus exposed is known as weathering. Under ordinary conditions it involves both mechanical and chemical changes in the rocks exposed at the earth's surface.

Temperature changes and the frost are the most active agents in producing mechanical disintegration in the rocks exposed at the earth's surface. Where naked rocks are exposed to the direct rays of the sun during the day, the outer layers of rock become heated and, therefore, expand. As rocks are poor conductors of heat, only a comparatively thin outer shell is affected. At night, these same rocks are cooled from the surface inward and contract, the outermost portions cooling off first while a little further down the rock is still heated. This causes stresses to be set up in the rocks which after a time are sufficient to cause the rock to exfoliate or split off from the surface. Crevices and fissures in the rocks are also slowly widened by these stresses.

Most rocks consist of aggregates of more than one mineral. Each of these minerals has a different coefficient of expansion. When, therefore, the temperature rises, the minerals expand and crowd against each other, and when the temperature drops, they contract and draw farther apart. The stresses thus produced by the unequal expansion and contraction of the minerals making up a rock will cause the formation of small cracks, by which water gets access to the rock and sets up chemical action, or in which roots of plants get a hold and further disintegrate the rock.

Most rocks are traversed by fractures and cracks of various kinds running in different directions. Many are also porous. Water gets into these openings and, if the temperature drops

sufficiently, freezes. In doing so it expands about one-tenth of its original volume and exerts a pressure of about one hundred and fifty tons to the square foot. Where the entire opening is full of water at the time freezing occurs, a tremendous force is thus exerted on the rock which tends to disrupt it. In this manner rocks are broken down into smaller and smaller fragments at the earth's surface.

In addition to the above mechanical disintegration of rocks, weathering also involves chemical decomposition of the constituent minerals. Moisture, especially when it condenses in the form of rain, is the most active agent in the atmosphere in producing this change. A part of the rain which falls on the earth's surface evaporates again, and passes into the atmosphere, a part runs off the surface and finds its way into the streams, while a third portion soaks into the ground. It is this portion which is the active agent in producing chemical decomposition of the mineral components of the rock.

Rain water always contains in solution varying amounts of the gases present in the atmosphere. Among these, oxygen and carbon dioxide are the most active chemically. As has already been stated practically all rock masses are traversed by fractures and cracks of varying size and the rocks themselves are more or less porous. The water which soaks into the ground traverses these crevices in its downward course and thus comes in contact with the minerals of the rock, which it attacks.

The most important chemical reactions which result are hydration, oxidation, carbonation, and solution. Hydration consists in the absorption of water which results in the production of hydrous minerals. Oxidation consists in the conversion of compounds of a lower state of oxidation into ones of a higher state. Carbonation consists in the union of carbon dioxide with bases to form carbonates. Carbon dioxide tends to replace silica in the silicates. Many of the new compounds thus formed are more or less soluble in water and are, therefore, dissolved by the ground water as it percolates through the rock and are carried away in solution.

As a result of these processes of weathering a loose mantle of material accumulates over the rocks exposed at the earth's

surface wherever the various agents of transportation such as water and wind are not sufficiently active to remove it as fast as it forms. Soil is the term commonly applied to this mantle. It consists of unaltered or only partially altered fragments of the original rock in addition to the various secondary minerals derived from the alteration of the original minerals, which made up the rock from which it is derived. Certain of the rock making minerals are readily attacked and, therefore, disappear in the soil being represented only by their alteration products. The mineral orthoclase which is an important mineral in many igneous rocks may be taken as an example to show how the agents of the atmosphere attack and decompose a mineral. The reaction is as follows: —

$$2KAlSi_3O_8 + 2H_2O + CO_2 = H_4Al_2Si_2O_9 + 4SiO_2 + K_2CO_3.$$

Orthoclase — Water — Carbon Dioxide — Kaolin — Quartz — Potassium Carbonate

In the above case the kaolin remains behind in the soil as a soft clayey mass. The silica when first liberated is a little more soluble and may in part be carried away in solution to be precipitated at lower levels in the form of quartz. The potassium carbonate is readily soluble in water and goes into solution. In part it is taken up by plants, and in part it is carried away by the circulating ground waters. Most of the other rock making minerals are attacked in a similar manner, some more and some less readily than orthoclase. The resulting products form a loose soft clayey mass. The mineral quartz on the other hand, which as has already been stated is also an important component of many rocks is very resistant and is practically not attacked at all by the above agents of weathering. It still remains in the residual mantle formed after the process of weathering has gone to completion.

The little grains of quartz of the original rock are, therefore, distributed through the soft loose clayey material derived from the alteration of the other important rock making minerals. In order to obtain a quartz sand it is now necessary for one or more of the various transporting agents present in nature to remove this weathered material from its original position and

to separate the quartz from the clayey material in which it is embedded.

Running water is one of the most important transporting agents found in nature. A portion of the rain which falls on the earth's surface runs off over the surface carrying with it portions of the soil. This run-off collects to form streams which unite to make rivers. Weathered material is thus washed into the streams and carried along by them either in mechanical suspension or by being rolled along the bottom, the amount of material carried along depending upon the volume and velocity of the stream. Whenever the velocity of the stream is checked, deposition occurs. The coarser material is deposited first, likewise the heavier. A separation according to size and specific gravity, therefore results so that streams are sorting as well as transporting agents. The coarsest material, known as gravel, consists largely of more or less rounded fragments of unaltered or partially altered rock which have been washed into the stream. The next material in size is known as sand. This is made up of grains which about correspond in size to that of the minerals which made up the original rock. Sand carried by streams ordinarily consists to a large extent of quartz grains because, as has been pointed out, the other common rock making minerals tend for the most part to become decomposed by the process of weathering into soft readily pulverized secondary minerals which give rise to the fine silt and clay carried by streams. The relative percentage of quartz present in the sand will depend largely upon two factors. The first of these is the relative amount of quartz present in the original rock which is yielding the sediments. If a sand is being derived from an already pure quartz sandstone, naturally it will consist almost entirely of quartz grains. The second is the degree of completion which the process of weathering had attained before the material was washed into the stream. Quartz is also harder than the other common rock forming minerals so that it does not suffer so much from wear, due to attrition of colliding grains during transportation, as do the other minerals present in the sand, which are gradually worn to a fine silt. The finest material, the silt and clay carried in mechanical suspension by streams,

consist largely of secondary minerals formed by weathering such as kaolinite, limonite, etc. This is the last material to settle when the velocity of the stream is checked.

Streams deposit the material which they carry in mechanical suspension at various places along their courses and at their mouths. As has already been indicated deposition occurs whenever there is a decrease in velocity. Where streams flow from mountainous regions onto plains, large deposits of sediments in the shape of huge alluvial fans and cones are often built up. At the foot of a mountain range where this adjoins a plain a number of fans may coalesce to form a large alluvial plain. As a rule sorting is very imperfect in these deposits and, therefore, sand of sufficient purity for glass making is rarely found in them. At times, however, if the stream is deriving its material largely from an already fairly pure quartz sandstone formed during some previous geologic period, fairly pure quartz sands may accumulate under these conditions. The Pottsville sandstone of Western Pennsylvania formed during the early part of the Pennsylvanian period represents such a deposit.

Streams also deposit considerable amounts of material at various places along their courses, especially along the lower portions. Sand deposits are often laid down upon the flood plains of rivers. At times these deposits are of sufficient purity to be used in the manufacture of glass, particularly the cheaper grades. Such deposits were formerly operated along the Monongahela River in the vicinity of Bellevernon, Pennsylvania.

Finally all material still carried mechanically by the stream when it enters a body of standing water is deposited at or near the mouth of the stream. Here sorting is usually more perfect. The coarse material or gravel comes to rest first, then the sand, and finally the mud and silt. When the stream enters a large lake or the ocean wave action further assists in the sorting by washing out the finer material from the sand. In the case of the ocean the waves, the undertow, the rising and falling tides, and the shore currents, due to waves striking the shore at an oblique angle, all assist in this sorting so that at times deposits of nearly pure quartz sand accumulate along the shore. The attrition of the grains also slowly wears the softer

ones down to a fine powder which is washed away leaving eventually only the harder ones like quartz behind. If the coast is a gradually subsiding one, the deposits may reach a thickness of several hundred feet. Sands running over 99 percent silica are reported as accumulating in this manner at the present time along the Gulf Coast of Florida in the vicinity of Pensacola and Tarpon Springs[3]. The Oriskany sandstone of Central Pennsylvania and Northeastern West Virginia is another such deposit laid down during the early part of the Devonian period.

Wind is another transporting and sorting agent which, at times in conjunction with running water or at times alone is instrumental in the accumulation of extremely pure quartz sands. The ultimate source of the material transported by the wind is also that derived largely from the products of atmospheric decay, which may or may not have been transported by water previous to the time they were taken up by the wind. Dry sand is readily blown about by the wind. Where the wind is in some prevailing direction it carries the sand along with it, heaping it up in the form of dunes which are hills of sand similar to the drifts formed in the case of snow which is being borne along by the wind. Figure 1 shows some typical sand dunes along the valley of the Rio Puerco at Adamana, Arizona. The larger grains of sand are carried along close to the ground while the finer particles or dust are carried to considerable heights. In this way the finer material is separated from the coarser. The unequal hardness of different minerals also plays an important part in the separation which occurs in wind blown sand. The grains do not have a cushion of water to protect them from abrasion from one another as they are blown along by the wind. The softer ones by the impact of the colliding particles are thus gradually reduced to dust which is blown away by the wind while the harder ones remain behind as sand. Quartz is among the hardest of the common minerals present, so that the more handling and sand receives from the wind the greater the percentage of quartz present

[3] *Mineral Resources of the United States, 1911, Part 2, U. S. Geol. Survey*, pp. 585-638.

becomes, until finally a practically pure quartz sand made up of well rounded grains results. The rounding of the grains may often be used as a criterion to distinguish wind blown sands from water laid ones, as the latter are usually more or less angular because grains the size of ordinary sand are protected from abrasion during transportation by the cushion of water around them. Victor Ziegler has carried on some experiments which led him to the conclusion that quartz grains less than 0.75 millimeters in diameter could not be rounded under water and, therefore, if they were rounded they were of wind

FIG. 1.

blown origin[4]. Wind worn grains also lose their glassy character and become dimmed by attrition so that the surface of the grains assumed the appearance of ground glass. Figure 2 shows a wind-blown sand from the Sylvania sandstone of the Silurian Period from Rockwood, Michigan, while Figure 3 shows an ordinary water laid sand from Bridgeton, New Jersey. Wind blown sands often accumulate along low lying sea coasts, along river flood plains in arid or semi-arid regions and over desert areas. The St. Peter sandstone, quarried so extensively for glass sand in the vicinity of Ottawa, Illinois and St. Louis,

[4] *Journal of Geology, Vol. XIX*, pp. 645-654, 1911.

Missouri, is an example of a wind blown sand deposited on a low lying coastal plain during the early part of the Ordovician Period.

Sands which are deposited over a gradually subsiding area may become buried to considerable depths by later sediments laid down on top of them. If a little clayey material was deposited along with the sand the pressure of the overlying rock

Fig. 2.

may be sufficient to compact the mass into a rock. At other times the sand is consolidated into a rock by mineral matter deposited between the grains from water solutions percolating through the sand. The most common cementing agents are silica (SiO_2), calcite ($CaCO_3$), dolomite ($CaCO_3$ $MgCO_3$), and iron oxides, usually the hydrated ferric oxide known as limonite, but also the simple ferric oxide, hematite. Where iron oxides form the bond, the sandstone is rendered unfit for

glass making. Deposits of sand and sandstone formed as outlined above may during a later stage in the geologic history of a region become elevated to varying heights above sea level. Erosion may remove the overlying sediments and expose the sandstone at the surface.

At times also in its geologic history a region, which has undergone gradual subsidence over a considerable interval of

FIG. 3.

time with the deposition of a thick series of sedimentary rocks, may be subjected to a period of folding due to lateral compression produced by the gradual shrinkage of the earth. The horizontal layers of rock are then thrown into a series of arches and troughs called anticlines and synclines. The beds thus become tilted at various angles. The great pressure brought about by this lateral compression acting in conjunction with a somewhat higher temperature due to the burial of the rocks

to a considerable depth beneath the earth's surface often causes considerable recrystallization to occur in the rock so that a sandstone is converted into an extremely hard and tough quartzite. Small amounts of water present between the grains of sand also assist in this recrystallization. During this process the original grains become entirely obliterated and a clear quartz-mosaic results. Figure 4 shows the appearance under the microscope between crossed nicols of a thin section of such a quartzite from the Oriskany formation near Mill Creek, Pennsylvania.

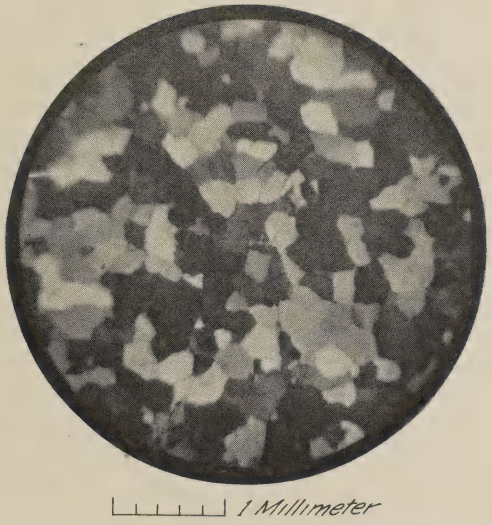


FIG. 4.

When the sandstone is again elevated above sea-level by movements underneath the earth's surface and exposed to weathering by the processes of erosion, the tendency is to convert it into loose sand. The rate at which the agents of weathering disintegrate it depends largely upon the bond. A sandstone with calcite as a bond, for example, disintegrates much more readily than one with silica, clayey material, or iron oxide, because calcite is comparatively readily soluble in water containing carbon dioxide. But even in the case of those in which silica is the bond, disintegration generally proceeds. At and near the

surface, therefore, sandstones often become quite friable and can be readily crushed to sand which can be used for glass making purposes if the stone is sufficiently free from deleterious constituents.

As has already been stated a sand deposit or a sandstone in order to be of value as a source of silica for manufacturing glass must be made up almost exclusively of quartz grains. An ideal sand or sandstone for glass making would contain nothing but quartz grains. Inasmuch as absolutely pure quartz sands or sandstones are not found in nature, however, it becomes necessary to determine what impurities are permissible and to what amount they may occur in a sand and still not render it unfit for the manufacture of glass. This depends largely on the kind of glass for which the sand is to be used. Optical and high grade lead flint glass require a much purer sand than ordinary window or bottle glass. The size and shape of the grains is a factor which should also be considered but this is not nearly so important as the chemical composition of the sand.

When a quantitative analysis is made of a glass sand there are usually found, in addition to the silica, small percentages of alumina, iron oxide, magnesia, lime, water, and titanium oxide, also occasionally a little sodium and potassium oxides and possibly a little organic matter. This is due to the fact that there are usually present, even in the purest quartz sands, minute amounts of other minerals such as mica, — especially muscovite and sericite, — feldspar, — including orthoclase, microcline, and plagioclase, — hornblende, magnetite, ilmenite, rutile, titanite, zircon, apatite, chlorite, kaolinite or other hydrated aluminium silicate, limonite, hematite, calcite, and dolomite.

Alumina usually occurs in glass sands in one or more of the following forms: — As orthoclare ($KAlSi_3O_8$), as plagioclase ($mNaAlSi_3O_6 + nCaAlSi_2O_8$), as muscovite H_2 (K, Na) Al_3 $(SiO_4)_3$), and as kaolinite ($H_4Al_2Si_2O_9$). The latter is of the most frequent occurrence. The small quantities of clayey material associated with most sand deposits consist largely of this mineral or some very similar hydrated aluminium silicate. Kaolinite and muscovite can be removed from the sand, at least in large part, by washing. Grains of unaltered feldspar on the

other hand can not be separated from quartz grains in this manner.

There is still some difference of opinion among glass manufacturers in regard to the effect of alumina in the sand on the glass. Some regard it as a harmful constituent in the sand, while others do not. In fact there is considerable evidence to show that in the case of certain glasses it is even advantageous to have it present in small quantities.

Dralle[5] cites a number of examples and gives the results of experiments which indicate that alumina in glasses high in lime tends to reduce their tendency to devitrify. Hovestadt also cites an example which occurred in actual practice. This was a thermometer glass made in the Thuringian Forest District of Germany, which would stand repeated melting, blowing, and fusing without change, while ordinary glass, such as is used for windows, becomes rough and dull of surface after even short exposure to the flame. Upon inquiry it was found that the Thuringian glass owed its special properties to a certain sand used in the making which was only found in the neighborhood of the village of Martinsroda. Upon analysis it was found that the Martinsroda sand contained 3.66 percent of alumina. Experiments with pure quartz sands to which this amount of alumina had been added gave exactly the same results as the Martinsroda sand, showing that the special properties imparted to the Thuringian glass by the Martinsroda sand were due to its alumina content. Schott suggests that the presence of the alumina hinders the volatilization of the alkalies at the surface of the glass, but it is also possible that the dulling of the glass is due to incipient crystallization or devitrification and that the alumina tends to prevent this.[6] R. L. Frink[7] has also observed that when alumina exists to the extent of 3 or 4 percent in a finished glass, this glass is not nearly so susceptible to the carbonizing or reducing action of the fire, or to the formation of cords and strings, or the production of a laminated condition, whether soda or salt cake be used for supplying the soda content.

[5] *Die Glasfabrikation* von Robert Dralle, 1911.
[6] *Jena Glass and its Scientific and Industrial Applications* by Dr. H. Hovestade, translated and edited by J. D. Everett and Alice Everett, 1902.
[7] *Transactions of the American Ceramic Society, Vol. XI,* pp. 99-102, 1909.

Dralle states and cites experiments indicating that alumina has a very favorable influence upon the durability of glass and decreases its solubility in water, weak acids, etc. Frink[8] has found the same thing to hold true in the case of a comparison of analyses of a large number of bottle glasses.

C. J. Brockbank[9] has called attention to the fact that the blue color in the case of glasses where salt cake has been used in the batch is not altogether due to iron present as an impurity but is due to the formation of compounds of sulphur and alumina analogous in composition to ultramarine blue which consists of sodium, aluminium, silicon, sulphur, and oxygen.

Alumina also has certain favorable influence on the physical properties of glass. Frink states that from his observations[10] alumina has the tendency to increase the surface tension when the surface is rapidly chilled. This is a valuable property in the manufacture of glass in molds for when a glass containing three to five percent alumina has been gathered or ladled from a mass of open metal at a temperature of about 1150° C., its surface immediately becomes lower in temperature dropping to about 825° C. and the skin or overlying stratum becomes very tenacious. When glass of this character is placed into the molds and pressed or blown, it has less tendency to take the various small imperfections in the mold, but at the same time it is sufficiently plastic to be forced into any desired shape. Alumina is an especially valuable constituent in the manufacture of bottle glass because it reduces the coefficient of expansion and increases the tenacity of the glass. It also facilitates annealing because a bottle will stand much more severe usage without breaking, and the glass does not require annealing to be conducted in as careful a manner as should be done with other glass. An alumina glass is also somewhat harder and a little more brilliant than ordinary glass.

One of the unfavorable properties of alumina is that it decreases the fusibility of the glass and increases its viscosity when present in amounts exceeding three percent. Also glass con-

[8] The Requirements of Glass for Bottling Purposes, by R. L. Frink, pp. 706-727. *Transactions of the American Ceramic Society, Vol. XV*, 1913.

[9] The Technical Control of a Window Glass Tank Furnace by C. J. Brockbank. *Transactions of the American Ceramic Society, Vol. XVII*, 1915, p. 225.

[10] *Transactions of the American Ceramic Society, Vol. XI*, pp. 99-102, 1909.

taining alumina does not mix well with other glass to form a perfectly homogeneous glass, free from cords. Care must, therefore, be exercised in using such glass as cullet.

The above observations lead one to conclude that for all ordinary varieties of glass the small percentages of alumina usually present in glass sands do not have any injurious influence on the glass but if anything are beneficial. Frink cites an interesting case[11] where a glass sand containing 7.26 percent alumina and .31 percent of ferric oxide gave a glass of superior physical properties to that of a sand containing only .68 percent alumina and ferric oxide. The glass made from the first sand contained 70.51 percent silica, 5.98 percent alumina, .23 percent ferric oxide, 9.57 percent lime, .81 percent magnesia, and 12.87 percent sodium oxide, while that from the second or purer sand contained 72.01 percent silica, 1.81 percent alumina and ferric oxide, 12.48 percent lime, .41 percent magnesia, and 13.21 percent of sodium oxide. The former showed an increased resistance to tension of 8.3 percent, an increase of 21.1 percent in modulus of rupture, and had a higher luster and remarkable power of resistance toward alkalies and was not attacked as readily by acids. It also annealed readily but was somewhat more susceptible to changes in temperature and had a considerable higher viscosity at given temperatures. For special glasses such as those used for optical purposes, however, alumina must be absent or present only in minute traces in the sand.

Iron occurs in glass sands both in the ferrous and ferric conditions. It is usually present as limonite ($Fe_2(OH)_6Fe_2O_3$), hematite (Fe_2O_3), or magnetite (Fe_3O_4), but sometimes such minerals as ilmenite, hornblende, and chlorite present in small quantities in the sand also contribute toward the iron content. Limonite usually occurs either intimately mixed with the kaolinite or other hydrated aluminium silicates which form the small amount of clayey material associated with sand, or as thin films coating the little sand grains or penetrating and filling minute crevices in them due to fracturing. In the former case it may be largely removed by washing, while in the latter it cannot. Sands that are cream colored, yellowish brown, or brown contain

[11] *Transactions of the American Ceramic Society, Vol. XI*, 1909, pp. 296-319.

limonite, the shade of color depending upon the amount of limonite present. Hematite colors a sand reddish brown. The color of the sand cannot always be taken as a criterion of the amount of iron present, however, as a light colored or nearly white sand may contain sufficient magnetite, ilmenite, or other iron bearing minerals to make the iron content higher than that of a yellowish brown sand containing iron in the form of limonite. When iron is present largely as magnetite or ilmenite in a sand it may be removed by a magnetic separator.

Iron is the most detrimental impurity found in glass sands on account of its coloring effect upon the glass. Ferrous iron gives glass a bluish green tint. Because nearly all glass contains at least traces of iron, when it is viewed through a thick section it always has a greenish cast. The color becomes more intense as the percentage of iron increases, so that ordinary bottle glass which contains a relatively high percentage of iron is often spoken of as green glass. Ferric iron on the other hand gives the glass a yellow tint which is not nearly so noticeable. Certain decolorizing agents such as manganese dioxide, nickel oxide, and selenium are often added to glass batches to neutralize the coloring effects of the iron where this is present in only small percentages.

The percentage of ferric oxide which may be present in the sand depends upon the kind of glass which is being manufactured. In the case of optical and the best grades of crystal or lead flint glass if the other raw materials are very pure the percentage of ferric oxide in the sand may run up to 0.02 percent according to Dralle. Rosenhain places the upper limit as high as 0.05 percent.[12] For plate glass Dralle gives the upper limit as 0.2 percent when the glass is viewed by transmitted light and 0.1 percent where it is used for mirrors. In the case of window glass, where thinner sheets are employed and the glass is viewed only by transmitted light, the iron content may run up to 0.5 percent but should not exceed this figure. This is also the upper limit permissible for white bottles. For ordinary green and brown bottles sands running from 0.5 percent to 7.0 percent are often employed.

[12] *Glass Manufacture* by Walter Rosenhain, New York, 1908.

Magnesium and calcium oxides are frequently found to be present in minute quantities in glass sands. They usually occur in the sand as carbonates. In most sands used for glass making, however, these percentages are so small as to be negligible. They have no detrimental influence on the glass. Lime is a part of the composition of most of the ordinary varieties of glass. Magnesia is much more apt to be introduced into the glass through the limestone employed as a raw material for lime than through the sand.

Where sand is used for the manufacture of the better grades of glass such as optical, lead flint, lime flint, and plate glass, it is usually dried artificially before it is introduced into the glass batch. For the cheaper grades of glass such as window and ordinary green bottle glass, wet sand is often employed. Where it is necessary to keep a close check upon the composition of the batch, dried sands should be used as the percentage of moisture in wet sands is apt to vary greatly from time to time and would make necessary numerous determinations of moisture content at frequent intervals. Most of the water in sand is present as little films adhering to the grains. A little, however, may occur in chemical combination with other elements in the form of such minerals as kaolinite, limonite, chlorite, or muscovite.

Whenever a determination for titanium oxide is made, a small amount is found in practically all glass sands. This varies from a few hundredths to a few tenths of a percent. Most of it is present in the form of little needles of rutile (TiO_2) which occur as inclusions in the quartz grains especially where these have been originally derived from igneous rocks. A little of it may also be present in the form of small grains of ilmenite $(FeTi)_2O_3$ or titanite $CaSiTiO_5$. The writer has not come across any data showing what influence titanium has on glass. The very small percentages usually present in glass sands are undoubtedly negligible as far as any influence on the properties of the glass is concerned.

Frink has called attention to the fact that small grains of ground pebbles (sometimes referred to as "ganister' by the glass men) when present in appreciable quantities occasionally produce small white stones in the glass because the temperature of

the glass furnace is not sufficiently high to cause them to go into solution in the molten glass.[13] According to Frink these pebbles usually consist of silicates of magnesium and lime or lime and alumina. They are silicate minerals, which were present in the original rock from which the sand was derived and which were not decomposed by the process of weathering and were not sorted out during transportation and deposition of the sand. Such pebbles can be distinguished readily when the sand is examined under the microscope.

The size and shape of the grains is also a factor of some importance in determining the value of a glass sand but usually this is only a matter of secondary consideration compared with the chemical composition of the sand. With regard to the most desirable size there is still a considerable difference of opinion. Many hold that the majority of the grains should not pass a sieve having 120 meshes per linear inch, that is the majority of the grains should be over .136 millimeters in diameter. On the other hand, the bulk of the sand should pass a 30 mesh sieve, that is the grains should have a diameter of less than .64 millimeters. This size, however, is not adhered to by all glass manufacturers and where the sand otherwise is nearly chemically pure, variations are permissable. One glass manufacturer in Pennsylvania has been using sand pulverized so as to pass a 100 mesh sieve in the manufacture of his finer grades of lead flint for cut glass articles. He holds that the sand thus reacts more readily with the other raw materials of the batch, as the quartz per given weight offers a relatively greater area of surface to be acted upon by the other ingredients of the batch than in the case of the coarser grains. It is doubtful, however, whether enough is gained in this way to pay for the extra expense incurred by having the sand pulverized to this fineness. When the sand is too fine there is apt to be a greater loss due to particles being carried away by the draft. This holds true in the case of tank furnaces, especially. Where the grains are uniformly larger than will pass a 30 mesh screen, more time is required to have them react with the other materials of the batch and go into solution in the resulting molten glass. This neces-

[13] *Glass Worker*, Vol. 31, No. 9, 1912, p. 2.

sarily decreases the output of the furnace per day. Too large grains are also apt to cause crystalline stones together with striae or cords to appear in the finished glass.

The following tables show the percentages of the various sized grains present in some typical glass sands:

DIAM. IN MM.	NO. 1	NO. 2	NO. 3	NO. 4	NO. 5
Retained on 10 mesh (1.65).....	.....	.....	.13	.....	.....
Through 10 mesh on 14 (1.168)..	.....	.42	.76	.....	.....
Through 14 mesh on 20 (.833)...	.07	.78	1.63	.04	.....
Through 20 mesh on 28 (.589)...	1.59	2.18	6.79	2.16	.02
Through 28 mesh on 35 (.417)...	13.11	7.28	14.76	19.81	.64
Through 35 mesh on 48 (.295)...	61.71	30.75	30.65	38.04	19.70
Through 48 mesh on 65 (.208)...	20.25	37.06	23.62	14.19	42.20
Through 65 mesh on 100 (.147)..	2.79	19.93	15.61	10.15	28.83
Through 100 mesh on 150 (.104).	.16	.85	3.91	6.66	7.08
Through 150 mesh on 200 (.074).	.03	.10	1.19	3.68	.60
Passed through 200 mesh.....	.01	.03	.75	4.76	.78
	99.72	99.38	99.80	99.49	99.85

No. 1. Keystone No. 1. Sand, Pennsylvania Glass Sand Co., Mapleton, Pennsylvania.

No. 2. Pittsburgh Plate Glass Co., Kennerdell, Pennsylvania.

No. 3. American Window Glass Company, Derry, Pennsylvania.

No. 4. Wedron White Sand Co., Ottawa, Illinois.

No. 5. American Silica Co., Rockwood, Illinois.

It was formerly thought that the sand grains should be sharp and angular in order to give the best results. With the opening up of deposits of exceptionally pure quartz sands and sandstones in the Mississippi Valley region around St. Louis, Missouri and Ottawa, Illinois, and in certain areas in Michigan, whose grains are well rounded, it has been found that these sands give excellent results in the case of all ordinary varieties of glass including lime flint, plate and window glass, and also lead flint for fine cut glass ware. The chemical purity of the sand produced is the important factor. In this connection it may be said, however, that in the case of two sands of like purity and

similar size of grains, the one in which the grains are sharp and angular is somewhat more desirable than the one which is made up of well rounded grains; because for the same size grain in volume and weight the angular grain has a greater area of surface exposed to the action of the other ingredients of the glass batch when melting occurs and, therefore, reacts with them more readily. Figure 5 is a photograph of an angular sand produced

Fig. 5.

by the Pennsylvania Glass Sand Company at its Keystone Works at Mapleton, Pa., while Figure 6 shows a well rounded sand produced by the Wedron White Sand Company at Ottawa, Ill.

Deposits of glass sand are found in nature in which the individual grains are not held together by a bond or cement of any kind but occur simply as bodies of loose, unconsolidated material. Often, however, the individual grains are cemented by a bond forming what is called a sandstone. In the latter case

it is necessary to crush this rock so that the bond between the grains again becomes severed and the rock is made to crumble into a loose sand. For glass sand only such sandstones are desirable as will break comparatively readily along the cement between the individual grains and not across the actual grains themselves. Very thoroughly cemented sandstones or quartzites are not desirable for glass sand as the process of crushing them

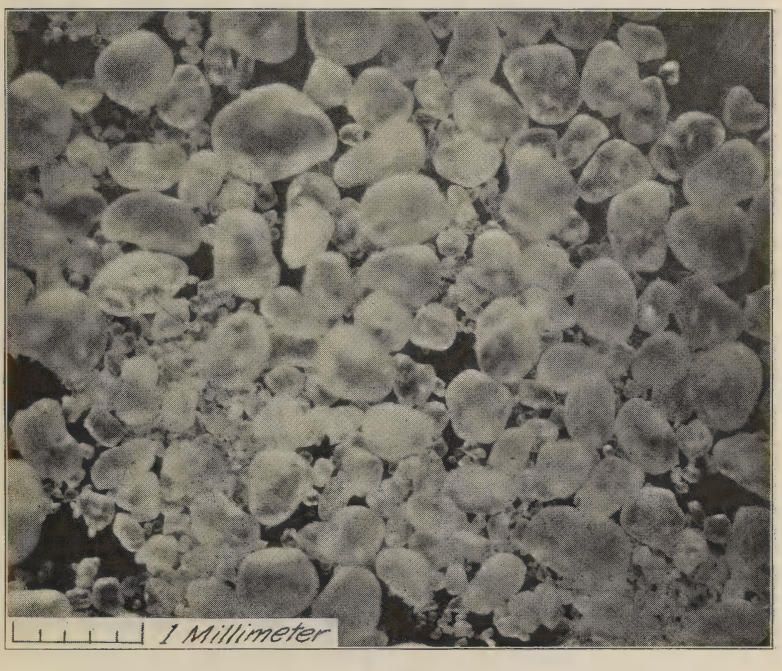


Fig. 6.

to the desired fineness is an expensive one, and much material of undesirable fineness results.

The method of treating a sandstone suitable for glass sand will be taken up first. There are two methods in common practice. One is to crush, wash, dry, and screen the sand, while the other is simply to crush and screen. The former method is used in the preparation of the better grades of sand used in the manufacture of lead flint, lime flint and plate glass, while the latter

method is occasionally used for the cheaper grades used in the manufacture of window and ordinary bottle glass.

By washing the sand the fine clayey material consisting largely of kaolinite or some other hydrated aluminium silicate with usually a little limonite mixed with it is removed from the sand. This operation, therefore, reduces the alumina and ferric

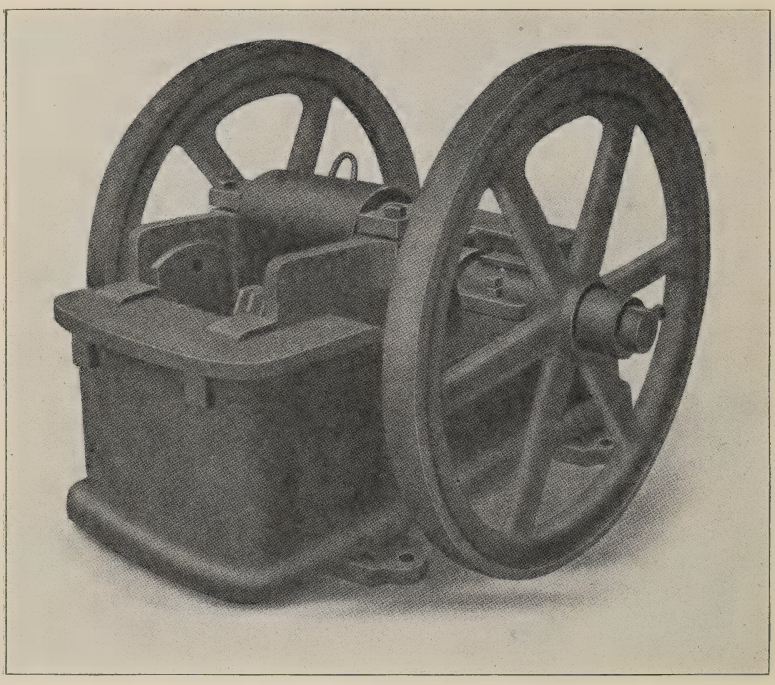


Fig. 7.

oxide content of the sand. Where there are appreciable quantities of limonite mixed with the clayey material, therefore, it is important that the sand should be washed carefully. If on the other hand, the iron is present in the sand as magnetite or some other mineral which occurs as little grains or if the quartz grains themselves are coated with a closely adhering film of iron oxide, washing does not improve the quality of the sand to any extent.

In the wet treatment, the sandstone as it comes from the quarry is first passed over a grizzly consisting of a series of parallel steel rails placed about two inches apart on an incline. The fine material drops into the slots between the rails while larger pieces pass over into a jaw crusher. The Blake type of jaw crusher of which Figure 7 is an illustration is the one usually employed. A 20 by 12 inch crusher handles from 14 to 25 tons of material per hour, depending upon the nature of the rock crushed, reducing it down to about a three inch diameter. From

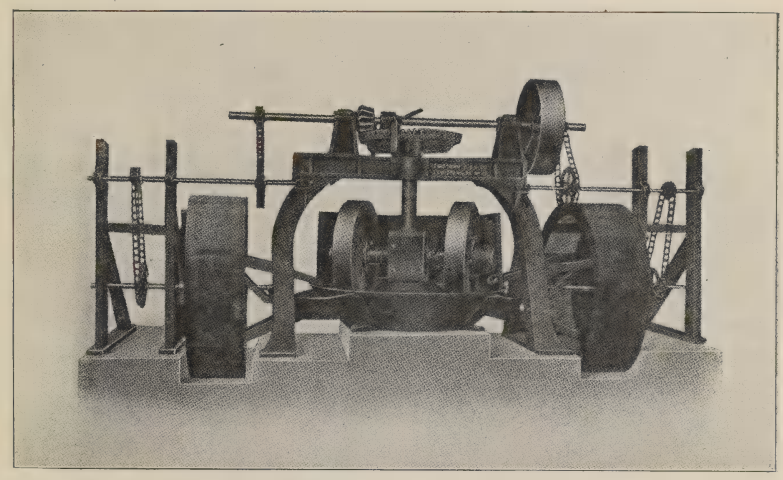


Fig. 8.

15 to 25 horse power are required to operate it. The speed is 250 revolutions per minute.

The material from the jaw crusher and that which passed through the grizzly next goes directly to a chaser mill or grinding pan like that shown in Figure 8. These mills consist of circular steel pans varying in diameter from 6 to 9 feet in which two heavy steel rolls or mullers mounted on a horizontal axis revolve. The pan itself is stationary. Water is fed into the pan and the material as it is crushed passes out through screens at the sides. Two opposite ends of the pan are usually perforated for this purpose. The capacity of the mill varies with the diameter of the pan and the hardness of the material treated. A

nine foot pan will handle anywhere from 100 to 250 tons of material per day of ten hours, depending upon the readiness with which the sandstone crumbles under the mullers. For a nine foot mill, the rolls usually have a 12 inch face and weigh from 5,000 to 6,000 pounds each. About 35 horse power are required to operate such a mill. The mullers revolve about a central shaft at about 30 to 33 revolutions per minute.

From the chaser mill the crushed material goes to a revolving screen. Sometimes only one screen is used and sometimes two placed at opposite sides of the pan. Figure 8 shows these screens in place. They have a diameter of 7 to 8 feet and a 24 to 36 inch face. They revolve about a central spindle at about 15 revolutions per minute. These screens are made of brass wire with usually 10 to 12 meshes per linear inch. The undersize material passes through the screens to the washers while the oversize is returned to the chaser mill. Occasionally when there is apt to be considerable coarse material present, the sand is run through two of these revolving screens, the first one having only about six meshes per linear inch while the second has twelve. This is done so as to protect the finer screen with the smaller diameter wire from too rapid wear by abrasion from coarse particles of rock.

From the revolving screens, the undersize material goes to the sand washers. These consist of inclined wooden boxes or troughs 10 to 12 feet long and 18 to 22 inches wide on the inside. In these troughs are cast iron rotating screw conveyors with wide blades which carry the sand from the bottom to the top of the troughs. Figure 9 shows the appearance of these screw washers. About one horse power is required to operate each screw. The washers are set up in batteries of two, three, four, five, and sometimes six. They may be set up either parallel to one another as shown in Figure 9 or in tandem. The troughs are inclined at angles varying from 18 to 20 degrees from the horizontal. The sand enters each washer at the foot while water runs in at the head. The revolving screws thus carry the sand up the trough against a stream of water which carries away with it the fine clayey material present in the sand. Where the washers are arranged in parallel, when the sand reaches the head

of one washer it is dumped into a trough and is carried to the foot of the next by a stream of water. It passes on up this washer in a similar manner and thus on through the other washers of the battery. Where they are set up in tandem they are so arranged that one washer discharges into the lower end of the next and so on through the series.

A plant with a nine foot grinding pan requires a least 150 gallons of water per minute. In some plants 400 to 600 gallons are used. An adequate water supply, therefore, is an absolute necessity for a washing plant of this type.

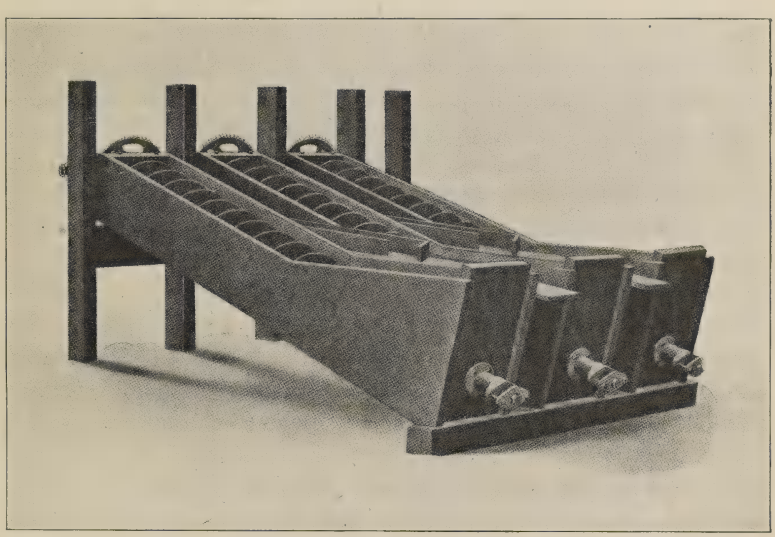


Fig. 9.

If the sand is to be shipped wet it is ready for the cars after leaving the washers. If it is to be dried, it next goes to the draining sheds where the excess water is allowed to run off. The sand from the washers is discharged onto a rubber belt conveyor inclined at the end near the washers and horizontal at the end over the draining floor. The belt runs near the roof of the draining shed, and the sand is allowed to drop so as to build up large cones reaching from the floor to the belt. These sheds ordinarily have sufficient length so that by discharging at

various points along the belt several of these cones of sand may be built up. The sand is usually allowed to drain at least twelve hours.

There are several types of dryers in use. Of these the steam dryer is the most recent invention and is gradually replacing the others. Steam dryers as a rule are built in sections about 20 feet long, 8 feet wide, and 6 feet high with hopper shaped bottoms. The walls of the dryer are built of ordinary red brick. Inside are horizontal steam pipes resting on inverted angle irons. These pipes are arranged in tiers one above the other and are placed closer and closer together toward the bottom of the dryer. The sand is discharged onto these pipes from a belt conveyor running over the dryer, gradually drops down between them, and is finally discharged onto another belt conveyor at the bottom of the dryer. The pipes are heated by passing steam through them. This evaporates the water in the sand. The steam and damp air accumulate under the angle irons on which the pipes rest and are drawn off by means of an exhaust fan.

Direct heat dryers are also used in the drying of sand although they are not so popular as formerly, and in many plants they are being replaced by steam dryers. The Cummer Salamander type of direct heat dryer is a style of this kind of dryer found in many sand plants of the Eastern United States. A Cummer dryer consists of a revolving steel plate cylinder carried on steel tires which run on steel rolls at each end. The rolls are supported on structural steel foundation plates. Compound gearing is used for revolving the cylinder with a reduction of ten to one. The wet material is fed continuously into the dryer at one end through a feed spout and is discharged continuously at the rear end dried. The heated gases resulting from combustion in the furnace, pass into a large commingling chamber which extends the entire length of the dryer cylinder. This cylinder which revolves slowly, has a great many large square openings in it, each of which is covered with a cast iron hood or cap. A number of hoods are put into each cylinder to allow about three-fourths of the heated air and gases to enter the cylinder through the rear end. The result is, there is com-

paratively little circulation at the rear end of the cylinder where the material is practically dry and often very dusty, and consequently, there is little or no dust blown out through the stack.

The fan which is located at the front or feed end of the dryer, draws the products of combustion from the furnace into the commingling chamber also the air through the registers in the side walls of the dryer, which reduces the temperatures toward the rear end of the dryer cylinder. The same fan draws the heated air and gases at different temperatures from the commingling chamber into the cylinder through the hoods in direct contact with the material being dried. The material immediately upon entering the cylinder commences to dry as it travels rearward toward the discharge, rapidly becoming more dry, while the temperatures of the heated air and gases are relatively lowered by the cold air coming in through the registers in the side walls of the dryer. The drying material is constantly cascaded in the cylinder and travels toward the rear or discharge end of the cylinder in the opposite direction to the heated air and gases. The air, gases, and moisture pass into the atmosphere from the cylinder through the fan. For drying glass sands, coke must be used as fuel. Where ordinary bituminous coal is used there is apt to be a coat of carbon formed on some of the sand grains on account of imperfect combustion. This is not permissible where the sand is to be used for glass making purposes.

Another type of direct heat dryer occasionally used consists of a brick stack about 35 to 40 feet high. At one side of this stack is a fire box. This is provided with artificial draft, air being forced into the fire box by means of a blower. A bucket elevator carries the sand to a point above the top of the stack down which it is allowed to drop. It is discharged at the bottom of the stack by means of a screw conveyor. The moisture in the sand is driven off by the heat from the rising products of combustion through which it falls. Coke must be used here as a fuel also for the same reason as in the case of the Cummer dryer.

One of the objections against the direct heat dryers is that, if they are not watched closely, the sand is apt to become heated

to a sufficiently high temperature to ignite any wood work with which it may come in contact after leaving the dryer. Disastrous fires have resulted from this cause. It is also claimed by those who have used both types that the cost of operating the steam dryers is cheaper.

The sand from the dryer is next screened. The size of screen varies with different plants, sizes from 14, 16, 18, 20, to 22 meshes per linear inch being employed. Eighteen meshes per linear inch is probably the most common size used. After the sand has been screened it is elevated to the storage bins ready for shipment.

Instead of the chaser mill or grinding pan for crushing the sandstone, other types of disintegrators are occasionally used. The Style "B" Triumph Disintegrator manufactured by the C. O. Bartlett Co., of Cleveland, Ohio, is adopted for breaking up sandstone of the type suitable for glass sand. The crushing apparatus consists of two sets of spokes made of high grade Swedish iron which revolve in opposite directions. The American Pulverizing Company of East St. Louis, also manufactures a pulverizer designed to crush sandstone to sand. The grinding is accomplished by means of revolving rings weighing about 27 pounds each, made of manganese steel or semi-steel chilled iron which are placed between grate bars of manganese steel. The rings and bars do not touch but as the sandstone is carried between them it is crushed by impact. The machine is operated at a speed of 600 revolutions per minute.

One of the difficulties encountered in using disintegrators and pulverizers of the above type to crush material, which is as hard as the quartz grains of a sandstone, is the excessive wear of the grinding parts. This makes it necessary to replace them at frequent intervals. Some iron is also introduced into the sand in this manner which of course is very objectionable especially in the better grades of sand.

For washing sand the Schutte and Koerting Company of Philadelphia have designed a water-jet sand washing device which operates on a different principle from that of the screw washers commonly used for this purpose. This consists of a series of iron boxes placed in one or more rows or in a circle.

In each of the boxes is installed a water jet eductor. The sand is admitted to the first box and stirred by means of a clean water jet. As it settles to the bottom it is lifted into the next box through the sand eductor operated by means of clean water taken from a pressure pipe underneath the box. As the sand is heavy it drops to the bottom of the box, while the water mixing with the clayey material on account of violent stirring, rises and overflows near the top. In this way there is obtained a cleansing of the sand by the use of clean pressure water only without the assistance of any mechanical means. It is desirable that the water should be as clean as possible, and the pressure at the eductor should be under a head of 30 to 40 feet.

Where the sand occurs as loose, unconsolidated material the necessary plant to prepare it for the market is much simpler. No jaw crushers, chaser mills, grinding pans, or other crushing devices are necessary, the sand going directly from the quarry to the washers. It may be loaded into cars and thus transported to the washers or if there is a sufficient slope from the quarry to the washers it may be washed into sluices by means of a stream of water played against the sand bank and thus transported to the plant. Sometimes if the bottom of the sand deposit is below the level of the washers it is first washed into a sump by means of a stream of water and then pumped through pipes to the washers by means of a sand pump.

Sometimes the cheaper grades of glass sand are not washed, the sandstone being simply crushed to sand and screened. When this method of preparation is used, a dry grinding pan is employed. In a pan of this type the mullers or rolls do not revolve about a central shaft although they turn about the horizontal axis on which they are mounted. The pan itself is rotated. The rolls tread on false plates which may be renewed when they are worn while the outer portion of the bottom of the pan consists of screen plates through which the crushed material passes.

After the material has gone through the grinding pan it is conveyed to a revolving or shaking screen from which the undersize is conveyed to storage bins, stock piles, or directly to the cars, while the oversize goes back to the pan.

Glass sands occasionally occur in nature in which most of the iron is present in the form of little grains of magnetite (Fe_3O_4), or ilmenite ($FeTi)_2O_3$). Both of these minerals are attracted by a magnet and, therefore, magnetic separation can be resorted to in order to lower the iron content of the sand. The writer, however, does not know of any sand plants where this is done and only of one glass factory where the sand used is treated in this way. Some iron also gets into the sand from the machinery. Quartz is a hard substance, and as the wearing parts of the machines in which the sandstone is crushed are of iron, the particles of iron get into the sand through abrasion. A magnetic separator removes these as well as the magnetite and ilmenite that may be present.

Kümmel and Gage have called attention to the fact that many of the minerals containing iron that are apt to be present in glass sands pass an 80 mesh sieve.[14] Cleansing the sands by screening is, therefore, possible. They carried on experiments in the laboratory with two samples and obtained the following results:

	BEFORE SCREENING	AFTER	BEFORE SCREENING	AFTER
	percent	*percent*	*percent*	*percent*
Fe_2O_3	.0068	.002	.0114	.0029
TiO_2	.117	.024	.024	.00434
Al_2O_3	.276	.085	.366	.106

These figures show that they were able to reduce the iron content of the sand to one-third or less, of titanium to one-fifth, and of aluminium to one-third or less. As far as the writer knows this method has never been tried out in actual practice.

Tscheuschner describes a rather expensive method for purifying yellow sands which contain considerable quantities of limonite.[15] For this purpose 64 parts of sand are sprinkled with 8 parts of water to which 3 parts of salt and 2 parts of concentrated sulphuric acid have been added. The whole is placed in a container lined with lead and allowed to stand for several months. The iron gradually goes into solution as chloride. Finally the sand is carefully washed and dried. This method

[14] *Annual Report of the State Geologist for the Year 1906. Geological Survey of New Jersey*, pp. 77-96.

[15] *Handbuch der Glasfabrikation, fuenfte Auflage*, Weimar, 1885.

was at one time used in Europe in localities where pure white quartz sands were not available, but with improvements in transportation facilities it became obsolete. Such methods have never been resorted to in this country on account of the ease with which high grade quartz sands, that require no such expensive treatment, may be obtained.

Before opening up a new glass sand deposit and installing the necessary machinery to prepare the sand for the market, a number of factors upon which the success of the enterprise will depend must be taken into consideration. Of course it is first necessary to determine whether the sandstone or sand deposit is of sufficient purity to be employed in the manufacture of glass. The size of the deposit must next be considered. A careful investigation should be made to determine whether it is sufficiently large to warrant the investment of the necessary capital for buildings, machinery, etc., which are needed to operate a glass sand plant.

Variations in the texture and composition of the sand or sandstone both across and along the beds should be looked for as these often occur on account of slight variations in the conditions under which the sand was deposited. Portions of a bed thus often become too high in iron to be used for glass manufacture, and this material has to be sorted out from the sandstone, which increases the cost of production. Limonite may also have been deposited by iron bearing solutions along fractures in the sandstone, thus rendering portions of it unfit for glass sand. Likewise lenticular masses of conglomerate often occur in beds of sandstone. On account of their pebbly nature these also have to be sorted out. Attention has already been called to the fact that the sandstone should be rather friable and the rock should break down fairly readily along the cementing material between the grains and should not be of such a nature as to break across the grains rather than along the binding material.

The geologic structure of the deposit must also be considered. If the beds are inclined or tilted it must be remembered that they can only be followed down their dip a relatively short distance until underground mining methods become necessary.

This can be done profitably only under special conditions, where the sand deposit is an exceptionally pure and extensive one and mining conditions are favorable. Where the beds are horizontal or nearly so, the amount of overlying material which will have to be stripped must be determined. There may be so much of it that the deposit cannot be worked at a profit.

Where the sand is to be washed, the water supply must be examined. Sometimes this factor is neglected, and sand plants are forced to shut down during the summer and early fall on account of a lack of sufficient water to wash the sand. This may mean a very serious loss.

The nearness of a market and transportation facilities are of extreme importance. Sand is a bulky material sold at a comparatively small margin of profit. The distance of various sand deposits from a certain market, therefore, will be a big factor in determining which ones will be able to compete for that market.

THE LATENT HEATS OF FUSION OF LIME AND MAGNESIA

BY EDWARD W. WASHBURN

The term "fusibility" as applied to a material, is intended to describe the relative ease or difficulty of liquefying this material. The factors which determine the ease or difficulty with which a material can be liquefied are (1) its melting point, (2) the quantity of heat which it absorbs in melting, that is, its latent heat of fusion, and (3) to some extent, its thermal conductivity. It is evident, therefore, that it is possible for one material to be more easily fusible than a second material which has a lower melting point. This would be the case where the second material had a much larger heat of fusion than the first material. It would be of some interest, therefore, in recording all of the significant properties of materials used for refractories to include latent heats of fusion as well as melting points, if the necessary data could be secured.

At the present time there exist practically no reliable data on the heats of fusion of refractory materials. Not even the order of magnitude of this property is known in most instances. The purpose of the present paper is to consider this problem for the purpose of ascertaining, if possible, at least the order of magnitude of this property in the case of some of our most refractory substances, in order to determine whether their low fusibility is to be ascribed in any appreciable degree to a large heat of fusion or whether it is due solely to a high melting point. For this purpose I have chosen to consider the rather extreme cases of lime and magnesia which represent two of the most refractory substances known, the melting point of magnesia being 5070°F. (2800°C.) and that of lime 4655°F. (2540°C.).

The most direct, and the customary, method of determining the heat of fusion of a substance which melts above, say, three or four hundred degrees, is to heat the material in a suit-

able furnace to some temperature a short distance above its melting point and then to drop the melted material into a calorimeter where it immediately crystallizes and gives up its heat of fusion to the calorimeter. If we attempt, however, to apply this method to high melting ceramic materials, we find in most instances that the material either fails to crystallize when it is dropped into the calorimeter, or else that only partial crystallization takes place, most of the material being obtained in the form of a glass. Under these circumstances, of course, either no latent heat of fusion is given up to the calorimeter or else only a part of it is given up, and in either case the method is a failure.

Another method which has been employed to some extent is based upon the cooling or heating curve of the material and depends for its success upon a knowledge of the heat capacity of both the crystalline and the liquid material in the neighborhood of the melting point. At best it is only a comparatively rough method, an accuracy of only about fifteen percent having being thus far obtained with it.

A third method which has not thus far, except in part, been applied to ceramic materials consists in determining the total heat capacity both of the crystalline and of the liquid material between room temperature and the melting point, and also determining the heat of solution, of both the crystalline and the glassy material in some suitable solvent. It seems probable that this method could be adapted to almost all ceramic materials and could be made to yield extremely accurate results. It would fail, however, in the case of a material which could not be obtained purely vitreous by rapid cooling.

One other method which is not subject to any of the difficulties of the preceding methods but which is very restricted in its applicability, is also available. It is this method which I propose to apply to the calculation of the heats of fusion of lime and magnesia. The method is based upon the laws of solutions and requires no calorimetric data.

At the present time we have a comparatively complete and perfect knowledge of all of the laws which govern the behavior of solutions made by dissolving, in one another, two materials

which resemble each other very closely in all their chemical and physical properties. In fact the more closely the two materials resemble each other the more accurately do the laws hold. For our present purpose we are concerned only with the freezing point-solubility law for such solutions. This is the law which expresses the relation between the composition of a solution and the temperature at which that solution will be in equilibrium with pure crystals of either of its constituents. This law is expressed by the following equations[1]:

$$log_{10} x_a = \frac{0.219\, L_a(T_a - T)}{T_a\, T}$$

and

$$log_{10} x_b = \frac{0.219\, L_b(T_b - T)}{T_b\, T}$$

The quantities in these equations have the following significance: A and B represent the two materials which make up the solution. x_a represents the molecular fraction of the substance A in the solution, that is, it represents the ratio of the number of molecules of A to the number of molecules of A plus the number of molecules of B. Similarly x_b represents the molecular fraction of the substance B. L_a and L_b represent respectively the latent heats of fusion of one gram-molecular-weight (called one *mole*) of each of the materials. T_a and T_b represent respectively the melting points of the two pure materials on the absolute centigrade scale. T represents the eutectic temperature of the system on the same scale.

Evidently from these equations the latent heats of fusion of each of the materials can be computed if we know the other quantities in the equations. As an example of the accuracy with which this law has been found to apply in certain cases. Table I is given. In this table a comparison of the eutectic temperatures obtained by direct measurement with those calculated from the above law, is set forth. The remarkably close

[1] A derivation and more detailed discussion or this freezing point law has been given by the author in another place (*Introduction to the Principles of Physical Chemistry*, McGraw-Hill Book Co., 1915, page 168).

agreement between the experimental values and the theoretical values will be noticed.

TABLE I — COMPARISON OF THE EUTECTIC TEMPERATURES CALCULATED FROM THE FREEZING POINT LAW WITH THE VALUES OBTAINED BY DIRECT MEASUREMENT.[2]

SUBSTANCE	MELTING POINT t	HEAT OF FUSION PER MOLE (CALORIES) L_F	OBSERVER	OBSERVED EUTECTIC TEMPERATURE tE	CALCULATED EUTECTIC TEMPERATURE
Benzene C_6H_6	5.48°	2370	Demerliac J. Meyer	Benzene-naphthalene	
				—3.48°	—3.56°
Diphenyl $C_6H_5—C_6H_5$	68.95°	4020	Washburn and Read	Benzene-diphenyl	
				—5.8°	—6.1°
Naphthalene $C_4H_4—C_2—C_4H_4$	80.09°	4560	Alluard Pickering	Naphthalene-diphenyl	
				39.4°	39.4°

Now the two substances lime and magnesia are so much alike that we may reasonably expect that their solutions will obey the above law. The melting points of the pure materials have been determined by Kanolt[3] and the eutectic temperature by Rankin and Merwin.[4] The melting point diagram for the system is apparently of the simplest possible type showing one eutectic, no compounds, and no mixed crystals. The composition of the eutectic melt was found to be 67 percent of lime and 33 percent of magnesia, the eutectic temperature being 2300° ± 50°C.

If we substitute these values in the above equations, we find for the latent heat of fusion of lime 28000 (±20 percent) calories per mole or 490 calories per gram, and for the latent heat of fusion of magnesia 28000 (± 15 percent) calories per mole or 700 calories per gram.

In Table II are shown the latent heats of fusion of a variety

[2] Measurements by Washburn and Read, *Proc. Nat'l Acad. Sci. 1*, 191 (1915).
[3] Kanolt. *Jour. Wash. Acad. Sci. 3*, 318 (1913).
[4] Rankin and Merwin, *Jour. Amer. Chem. Soc. 38*, 571 (1916).

of materials having comparatively large heats of fusion. Of the substances shown, the first three have very complex molecules and these molecules are known to break up partially on melting, so that the large apparent latent heats of fusion of these compounds may be caused partially by their dissociation on fusion. The silicates shown in the table are natural minerals and are also comparatively complicated in their molecular structure, so that a comparatively large heat of fusion per mole is not surprising. In the case of lime and magnesia, however, the molecular structure is very simple, but nevertheless we find that these two substances have much higher heats of fusion than any other materials about which we have any knowledge on this subject. It is evident, therefore, that the low fusibility of these two materials is due, in a considerable degree, to the large amount of heat which they absorb on melting. Thus, after having heated magnesia to its melting point, the amount of heat then required to liquefy it would be sufficient to convert an equal weight of ice into steam at 200° F.

TABLE II — HEATS OF FUSION (IN SMALL CALORIES) OF SUBSTANCES HAVING LARGE HEATS OF FUSION

SUBSTANCE	MELTING POINT C.	MOLECULAR WEIGHT M.	LATENT HEAT OF FUSION PER GRAM IF	LATENT HEAT OF FUSION PER MOLE L_F	OBSERVER
$Na_2CrO_4 10H_2O$ ...	23°	342.4	39.2	13,400	Berthelot[5]
$Na_2SO_4 10H_2O$	31°	322.4	48	16,500	Cohen[5]
$Na_2HPO_4 12\ H_2O$.	36°	358.4	67	24,000	Person[5]
Anorthite $CaAl_2Si_2O_8$ ..	1200°	279	100	28,000	Vogt[6]
Diopside $CaMgSi_2O_6$	1225°	217	100	22,000	Vogt[6] White[6]
Enstatite $Mg_2Si_2O_6$	1375°	201	125	25,000	Vogt[6]
Olivine Mg_2SiO_4	1400°	141	130	18,000	Vogt[6]
CaO	2570°± 3°	56.1	490±20%	30,000	
MgO	2800°±13°	40.3	700±15%	30,000	

[5] Berthelot, (*Compt. rend. 87*, 575 (1878)); Cohen, (*Z. physik. Chem. 14*, 86 (1894)); Person, (*Ann. chim. phys., 27*, 252, 259 (1849)). Direct calorimetric determinations.

[6] Vogt, (*Silikatschmelzloesungen*, 1904, pp. 65 and 68, part II); White (*Z. anorg. chem. 69*, 348 (1911)). Calculated from the cooling or heating curve. Possible error 15-20 per cent.

In view of the extremely high temperatures at which liquid solutions of magnesia and lime can exist in equilibrium with the crystalline materials, the propriety of applying the laws of solutions to these systems might be justly questioned, since, however exactly and universally these laws may be found to hold at ordinary temperatures, there is always at least a remote possibility that some unknown influence may exist at very high temperatures which would render them invalid.

Furthermore owing to the great difficulty of making equilibrium determinations at these high temperatures the correctness of Rankin and Merwin's diagram for this system might possibly be questioned. In view of these facts a direct calorimetric determination of the latent heats of fusion of these materials would be of considerable interest. Such a determination although rather difficult would by no means be impossible to accomplish.

PRINCIPLES CONTROLLING THE FORMATION AND REMOVAL OF BUBBLES IN MOLTEN GLASS

BY RAYMOND M. HOWE.

When a glass batch is subjected to heat, changes take place which depend upon the temperature, rate of heating, the ingredients, and the condition of the batch at that particular time.

As the temperature increases, first the moisture is driven off, the carbonates then begin to decompose, and any sulphates present may be broken up or reduced. In general the substances change into a more stable form. Subsequently, if the temperature increase is in accordance with practice, some of the ingredients begin to fuse. As this fusion progresses, and the decomposition of the batch continues, the gas evolved can no longer escape freely. As a result bubbles form which are often found in the finished glass. These are commonly known as seeds.

The difficulty encountered by the manufacturer in avoiding the formation of these seeds is common knowledge. As far as the writer knows, however, the principles involved in their removal have never been discussed in detail. For this reason it can not be expected that the problem is to be definitely solved, but it is hoped that this paper may stimulate interest along this line. Unfortunately the data available is meagre, and many assumptions must be made.

Classification. Before the removal of these bubbles can be discussed, it is necessary to classify them. This was attempted in an entirely original way, but in each attempt the result was practically the same as the classification suggested by Prof. Silverman before this Society[1].

The most important class will naturally include those bubbles arising from the decomposing ingredients of the batch. These bubbles may contain CO, CO_2, SO_2, SO_3, O_2, the oxides

[1] *Trans. Amer. Cer. Soc., Vol. XVII* — 800.

of nitrogen, etc. It can be seen at a glance that the substances forming such bubbles will exert an enormous vapor pressure at the fining temperature. These gases are all rather insoluble in glass at this temperature, and since conditions are such that they can not escape, they remain in the glass as bubbles or "seeds."

The second class of bubbles includes those resulting from the volatilization of some of the ingredients of the batch. A typical example of this is common salt.

These substances as a class are more soluble in the glass, and they do not possess such high vapor pressure. As a conclusion one would think that they could not exert such a great pressure within a bubble. If they were subject to greater pressure, more would go into solution according to the laws governing equilibrium between gases and liquids, and as a result they would not have such a great bubble forming power. Such substances, especially because of their low percentage in the glass batch, would be more apt to volatilize into bubbles already found.

It is believed that this would explain the case cited by Frink[2]. A very small amount of arsenic was introduced into the batch. A great number of seeds were observed, all of which contained some of the arsenic, but the arsenic by itself could hardly have been responsible for all of these seeds. If, however, the arsenic volatilized into small bubbles already formed, it would take but a small amount to make its appearance in a great number of bubbles.

The third class includes such bubbles as those which result from ingredients purposely introduced after the glass is fused (a potato, or arsenic). If introduced at this time their vapor pressures are very high. The rate of solution, if soluble at all, is low. As a result such substances hardly go into solution but volatilize rapidly, and as a result form bubbles.

The fourth class includes those bubbles introduced by accident. Those evolved during reheating, those introduced during gathering, etc., constitute this class. In this paper such bubbles will not be considered.

---

[2] *Trans. Amer. Cer. Soc. Vol. XVII* — 798.

Removal of Bubbles. Once these bubbles form they are subjected to several forces. The first force is due to the displacement of the light vapor by the heavy glass. This can be expressed mathematically by the following expression:

$$F = v(\rho - \rho')g \qquad (1)$$

F = upward force of the bubble. ρ = density of the glass.
v = the volume of the bubble. ρ' = density of the vapor
g = attraction of gravity.

By means of this the upward force of the bubble may be calculated. For very small bubbles it approaches zero as a limit, and for large ones this force become considerable.

Acting against this upward force is the frictional resistance of the glass. If the total resistance upon a bubble is represented by R, and K is the constant representing the frictional resistance of the glass at that temperature, and x represents the rate of movement of the bubble, an equation results, —

$$R = 6\pi Krx \qquad (2)$$

Unfortunately there is no material available on the frictional resistance of glass, so it is necessary to develop a comparison with viscosity. Barus has worked with the settling of particles in water and used the same formula for the resistance offered. (Barus, *Bull. 36, U. S. Geo. Sur.*). He found that the particles of a certain size would settle in water at a temperature of 15° at the rate of 3 cm./sec. 10^6. The same particles settled in water at a temperature of 100° at the rate of 30 cm./sec. 10^6. The viscosity of water at 100° is $^1/_6$ that at at 15°. In other words the particles at 100° settled ten times as rapidly as at 15°, while the viscosity decreased only six times. The greater proportionate increase in the rate of settling than the decrease in the viscosity was attributed to increased molecular activity. If now the broad term of frictional resistance includes this it can be said that the frictional resistance had decreased ten times while the viscosity had decreased six times. Applying this to the frictional resistance offered by glass to the upward passage of gas bubbles it may be said that the frictional resistance decreases as the viscosity decreases but in a greater

degree. If a viscosity curve for glass such as is given by Dralle is investigated, the following facts can be seen (Dralle, *Das Glasfabrikation, Vol. I.* p. 31). The viscosity decreases rapidly until a certain temperature is reached. In this case it is 1100°. Above this temperature the viscosity decreases less rapidly as the temperature is increased until a second limit is reached. This second limit in the particular example is 1500° As the temperature is increased further, the viscocity falls but slowly.

It leads to the conclusion that the frictional resistance offered by the glass to the upward passage of a bubble varies in much the same way. It decreases very rapidly up to the temperature of 1000° to 1200°, according to the composition of the glass. Beyond this temperature the decrease in frictional resistance per degree rise becomes smaller and smaller. In order, therefore, to make the value K so small as to be negligible, the glass must be heated to an extremely high temperature. This temperature, even if available, can not be used in practice. There is no refractory which could be used at such a temperature if the glass itself would stand such a treatment. Because of this, K will always exert a limiting influence upon the rate (x) at which the bubbles escape.

If the speed of the bubble in its upward passage is uniform, $F = R$ and the equations become, —

$$6\pi Krx = v(\rho - \rho')g \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$6\pi Krx = 4/3\,\pi r^3(\rho - \rho')g \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$x = 2/9\,r^2\,\frac{(\rho - \rho')g}{K} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$x = \frac{A r^2}{K} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

The constant A is inserted here to include the constant values 2/9, ρ, ρ' (which is in comparison with ρ small and may be neglected), and g.

The limits of K have been discussed. It is apparent, then from equation (6), that the dimension of the bubble is an ex-

tremely important factor in determining the rate (x) of its removal. If r is sufficiently small the bubble may be permanently retained, as shown by Maxwell.

By means of Stokes's formula, he found that if air were rarified 1000 times, and drops of water one half the diameter of a human hair (.0025 cm.) were introduced, they would fall at the rate of 2 cm. per second. However, if the radius were 1/100 as large, its rate would decrease 1/10000 (since it varies as r^2) and would be less than .1 cm. per hour.

The frictional resistance of glass is enormous in comparison to that of air rarified 1000 times. Since very small particles settle in the air slowly, they must therefore rise still more slowly through molten glass. As a result of this they would either be held in suspension or move at a negligibly slow rate.

In order to increase this rate, the radius of the bubble must be increased. This might be done in several ways. One way would be to expand the bubble by increasing its internal pressure. Another way would be to combine several bubbles to form a larger one. A third way would be to decrease the external pressure exerted on the bubble, as may be deduced from the general gas law, —

$$PV = RT$$

In each case however the size of the bubble becomes a function of pressure.

Bubbles approaching the top of the liquid do not expand to any extent. This shows that the hydrostatic pressure of the glass is not the force which controls the size of the bubble. If the pressure of the atmosphere is neglected, the remaining force which limits the expansion is the surface tension of the glass about the bubble. It is working against the gas pressure on the inside of the bubble, and the two forces are equal.

It is this force that is responsible for the shape of the bubble. Surface tension is a form of potential energy. Potential energy always tends toward a minimum. In order to have the smallest surface enclosing a given volume it is necessary to have the bubble spherical. Any variations from this shape are due to the introduction of other forces.

In order to calculate the pressures of various sized bubbles the inside gas pressure and the surface tension are equated (Hatschek, *Surface Tension*). If p is the inside pressure of the gas then the total pressure exerted on the sides of the bubble is equal to p x area of the greatest circle.

$$\text{Total pressure} = p\pi r^2 \qquad (7)$$

The surface tension is expressed by σ and it is working about the circumference of this same circle. The total force of this is expressed by the equation, —

$$\text{Total surface tension} = 2\pi r\sigma \qquad (8)$$

The two forces are equal,

$$2\pi r\sigma = p\pi r^2 \qquad (9)$$

$$p = 2\sigma/r \qquad (10)$$

σ is a constant for a fixed temperature and r may be any size. The inside pressure then varies inversely as the radius of the bubble. It is exceedingly great for small bubbles and small for large bubbles. This is an exceedingly important principle in the fining of glass.

Let us suppose a condition where very small bubbles are scattered throughout a glass batch in the molten state. Now let a substance be introduced which will form large bubbles. This is often done by introducing a potato. As these large bubbles form at the bottom of the melt they rise rapidly because of their large radius. The rate of ascent varies as the square of the radius, as was proved, and hence their speed upward is relatively great. These large bubbles are under a low pressure in comparison to the small bubbles with which they come in contact. The result is that the large bubble grows at the expense of the small one, and hence it rises still more easily. The difficulty encountered in all other methods of removing small bubbles is that the smaller they are, the harder they are to remove. In this case however the smaller they are the greater will be their inside pressure, and the more vigorously will they force their way into the large bubbles. If this principle is applied therefore in glasses of reasonable frictional resistance, all bubbles will be removed.

Another possibility of increasing the radius of a bubble

was by expansion. In order to do this the pressure must be increased in the inside of the bubble. This can be done by increasing the temperature. It is found, however, that small bubbles are again harder to expand than the larger ones.

$$4/3\pi r^3 = v \qquad (11)$$

$$r^3 = 3v/4\pi \qquad (12)$$

$$r = \frac{(3v)^{1/3}}{(4\pi)} = C_1 v^{1/3} \qquad (13)$$

C is a constant to include $3/4\pi$

$$pv = nRT \quad or \quad p = nRT/v \qquad (14)$$

(The general gas law where R is a constant and since a fixed amount of gas is within each bubble when considered from this standpoint, n is also a constant.)

$$p = 2\sigma/r \qquad (10)$$

$$\text{therefore } 2\sigma v = nrRT \qquad (15)$$

$$v = \frac{nRRT}{2\sigma} \qquad (16)$$

R is a constant. n is a constant. At this temperature 2σ does not vary appreciably. C_2 is therefore substituted for $\frac{nR}{2\sigma}$.

$$v = C_2 rT \qquad (17)$$

$$r = v/C_2 T \qquad (18)$$

Combining 13 and 18,

$$v/C_2 T = C_1 v^{1/3} \qquad (19)$$

$$v = C_1 C_2 T v^{1/3} \qquad (20)$$

C_3 is substituted for the two constants $C_1 C_2$.

$$v = C_3 T v^{1/3}$$

Taking the derivative to secure the rate of increase in volume with increase in temperature,

$$dv/dt = C_4 v^{1/3}$$

This shows that the rate of expansion depends upon a constant and the diameter of the bubble. A bubble of unit volume will only increase $1/2$ as much in proportion as a bubble of eight

times the unit volume. The temperature range is again limited, as it was in decreasing the frictional constant K. The conclusion is that small bubbles, since they will expand but little with the temperature range available, can not be completely removed by any possible expansion.

Summary. I. The removal of bubbles depends upon the frictional resistance of the glass and the square of the radius of the bubble. If x equals the rate then $x = Ar^2/K$.

II. K can never be made negligibly small, therefore extremely small bubbles can not be entirely removed by increasing the temperature. K can simply be made as small as is practical.

III. After K is made sufficiently small the radius of the bubble must be greater than a certain minimum value before the bubble will rise.

IV. Expansion of bubbles by increasing the temperature will not remove all bubbles.

V. The most certain way to assure the removal of all bubbles is by the introduction of large bubbles. The small bubble then passes into the larger one and passes out with it.

School of Chemistry,
University of Pittsburgh.

NOTE ON PINHOLING AND PEELING ON TERRA COTTA

BY HEWITT WILSON

Intermittently we have been troubled with peculiarly shaped pinholes in our glazed ware. They are small tongues of underslip rising through the glaze and leaving a clean hole to the body. The glazed surface becomes spotted as soon as dirt lodges in the small openings. Water or ink soaks readily into the body through these holes, and a distinct projection can be felt by rubbing the hand over the glazed surface. They are not merely the small blisters or holes in the glaze alone which are usually reported.

Observations. The following observations have been made:

(1). When the second coating of underslip or the first or second coating of glaze is sprayed onto the dried terra cotta, these tongues of underslip can be seen rising. They open slowly, not like the bursting of a bubble which stops as soon as the internal gas escapes, but as if there were a stretching or pulling action at a point of rupture. Exposing the body at this point usually shows a bit of grog or a hard substance, but exceptions to this are numerous.

(2). Rubbing the dried and glazed surface, until all the pinholes are pushed down and covered, does not stop them from showing as badly as ever after burning.

(3). Care was taken that there was no oil on the terra cotta, and all dust was thoroughly brushed away.

(4). Particles of plaster from the molds were not the cause of the trouble.

(5). The pinholes were not caused by the slip coatings or the first glaze coating being drier than the usual practice before applying the succeeding coat. When a wet glaze is sprayed onto some underslips which are partially dry, blistering will occur.

(6). Removing the surface with sand paper stopped the greater part of them.

(7). This trouble attacked all glazed ware and was worse in those glazes which flowed the least in firing. There would be more pinholes on an ashler piece than on an ornamental design.

(8). If the underslip were fired with no glaze covering, no pinholes showed. This was also true of our standard finish or vitreous coating.

(9). By respraying the burned pinholed surfaces with glaze alone and reburning, they were entirely filled and a good surface produced.

(10). The usual addition of barium carbonate to the clay body is about one-half of one percent. By raising this to about two percent and using the more soluble barium fluoride as part of this content, we could reduce the number of pinholes but could not eliminate them altogether.

(11). It was thought that the crystallization of a soluble salt added to the underslip would stop the peeling and probably the pinholes. One percent soda ash was used for several months but produced no noticeable difference in holding properties.

If the barium carbonate were left out of the body, peeling of the glaze and slip from the bared body was produced and also more pinholes were obtained. The edges would be loose and crumbly and the glaze as fragile as egg shells. Removing the glaze from an edge or peeled place revealed a brown discolored body. More pinholes would form on the loose edges than in other parts.

With or without barium carbonate we occasionally see a brown discoloration on the dried terra cotta before slipping, but these do not produce peeling nor pinholes.

Theory Advanced for Peeling and Pinholing. As the terra cotta dries, the soluble salts are carried to the surface. Depending upon the amount of barium carbonate these will come to the surface in large quantities and cover large areas densely, or small portions of the soluble salts, starting from sources near the surface, will merely collect on a projecting piece of grog, a surface irregularity or on an edge of a drying piece. If the soluble salt content is large, the chances for this escape from

the barium will be larger, and little points of salt deposition may be very numerous.

When the first coating of underslip is sprayed on, the dry body soaks up the water very fast, and the smooth wet coat hardens quickly. But when the second slip coating and the following glaze coats are applied, each to a water finish, there is an elastic film stretched over the surface. While this is still wet, the little tongues lift, due to the action of the points of salt crystals on the first coat of underslip which has been softened again by the wet coats above. This salt action may be likened to the thinning and thickening of the slips and glazes by the use of hydrochloric acid and soda ash. At least the slip is disturbed at this salt point, and the pulling of the surface tension causes a break at the weakened place and a rise of a broken portion of the dried first coat as the over-lying coatings contract with the escaping of the water.

Our underslip is a very plastic body containing 40 percent English ball clay and 40 percent English china clay. Our standard finish only has 12 percent English ball and 24 percent English china clays. The glazes contain only about 10 percent ball clay and 5 percent china clay. When the standards or glazes are sprayed directly onto the body, there will be no pinholes irrespective of additional coatings. Bubbles and blisters can be produced, however, with these low clay slips.

It is possible that a gas or air bubble could start the lifting action which would be finished by the surface tension, but these are usually larger in area than that covered by the pinhole action.

Attempts to Produce Pinholes. Several experiments were made to produce pinholes by addition of soluble salts: —

1. Grog was soaked with a saturated solution of magnesium sulphate and dried. After the excess coating on the surface had been washed off, the grog was again dried and used in the body mix with or without additions of barium fluoride and carbonate. All trials gave no indications of peeling or pinholing, when dry, during spraying or after burning.

2. The regular body mix which had stood in a bowl from which some potassium dichromate had not been thoroughly re-

moved, showed a distinct discoloration on the dried body and gave bad peeling but no pinholes when glazed and burned. This was but a minute quantity of the dichromate, as the bowl had been washed and the portion staining the clay had come from a crack and other rough parts of the inside surface.

3. Magnesium sulphate in powdered crystalline form was dusted onto the dry body surface before application of underslip and glaze. Likewise on another set of trials fine dry grog was applied to the surface. In spraying on the underslip the magnesium sulphate caused numerous tongues to lift and small bubbles to form. The latter most probably contained air which had been held around the crystals. They could be drowned by succeeding coatings. The grog dust gave air bubbles but no tongues. produced three times the number of pinholes that the grog had, but this was many times less than the number seen on regular ware when not wanted. We would think that in this concentrated form the glaze surface would have been badly broken with eruptions. The grog particles were buried completely or stood waist deep in glaze. Most of the pinholes in this case seemed to come from the body itself and not from the grog.

4. The phenolphtalein alkalinity test made upon red-burning shales of West Washington shows a slight alkaline reaction. There is no acid or alkaline reaction with the regular raw body, taken either from clean places or brown discolored edges. A shale body without barium will peel worse than the regular terra cotta body.

5. A clay "tea" was made by boiling 500 grams of ground terra cotta body clay with hydrant water, settling, decanting, and concentrating the liquid. This gave a brown color. A qualitative analysis made upon this liquid gave no inorganic salts. We are pretty certain as to the absence of iron but not of the alkaline earths. It should be checked. After soaking several white burned, English china clay test bars in the brown liquid, they were burned but gave no signs of any discoloration.

6. An evaporation analysis was made as follows: — Ground clay was dried at 200 degrees F. A five gram sample was boiled for 15 minutes in distilled water with three to four times its

volume of water. The slip was allowed to settle and then filtered through a burned clay filter (using suction), washed with hot water, and the filtrate evaporated to dryness and residue cooled in a dessicator.

This gave for three trials on the regular body mix, without barium, .114 percent, .128 percent and 160 percent soluble salts depending on the porosity of the filter and the amount of washing.

Two hundred cc. of hydrant water, approximately the amount used in a test of this sort was evaporated to dryness and gave .0158 gm. residue or .0079 percent.

7. Sulphur and Pinholing. Glazed samples were put in a small muffle kiln, and sulphur was added at the fire box to the burning coal and also thrown into the muffle when red hot. Pinholes appear in several patches which show a discoloration from sulphuring, but they are in the glaze alone and are not of the tongued variety. Sulphur was also plunged into the slip and glaze. Besides a slight dryness no disturbance was produced.

8. Tests with Barium Salts. Additions of various salts were made to the regular face clay which has been giving pinholes. This clay had .35-.4 percent barium carbonate added at the dry pan and had aged one week in the damp concrete cellars. The additions of salt were made by repugging the required amount (percent dry basis) with the wet clay to a wetter consistency.

Seven 3 in. by 5 in. trials or 105 sq. in. of surface were pressed from each batch.

Number.	*Salt.*	*Percent Added.*	*Number Pinholes.*
PH 1	None		60
PH 2	BaF_2	1.0	4
PH 3	BaF_2	2.0	1
PH 4	BaF_2	4.0	2
PH 5	$BaCO_3$	2.0	70
PH 6	$BaCO_3$	4.0	186
PH 7	$BaCl_2$	1.0	35
PH 8	$BaCl_2$	2.0	1
PH 10	$BaCl_2$ BaF_2	1.0 1.0	96

One percent barium chloride produced bad sticking to the molds and gave crowfooting to the glaze. A smaller percent should have been used as it is too readily soluble. The fluoride acted best of all, but it does not eliminate the trouble entirely.

9. When the PH 1 body samples were dry, five were water brushed with a 10 percent solution of barium chloride. This produced 140 pinholes per 105 sq. in.

When a 10 percent solution of barium fluoride was used 188 pinholes were produced per 105 sq. in. of surface.

10. We ordinarily use wood for heating the raw-clay dryer, but owing to a scarcity of this fuel, coal was used for one burn. This might have caused a formation of sulphates on the damp clay, as the products of combustion came in contact with the clay. But samples made from damp clay which had been sooted black with coal smoke and others with wood smoke gave no pinholes.

Use of Gum Arabic. Two per cent gum arabic sorts added to the underslip and 3 percent added to the glazes stopped all pinholing. Before, where a pinhole would rise there is just a small depression made shiny at a certain angle of vision by the separate reflection of the saucer shaped surface. The glaze coatings fill these, and no tongues of underslip protrude. When the gum is omitted from either the slip or glaze a few pinholes appear at times. The gum increases the slip strength and stickiness to such a point that the soluble salt action, surface tension of gas expansion can not break the surface. The dry modulus of rupture of the underslip was increased from 457 to 1060 or 603 pounds per sq. in. by the 2 percent gum addition.

There was no apparent change in the wet tensile strength, but this does not measure the stickiness or the plasticity of the slip.

Besides the elimination of the pinholes, the gum causes the underslip to hold tight to the body during the dry stage in which period it is easiest to let go. Also the glaze surface is hardened and is not easily broken nor dusted off in kiln setting. The ball clay content which had been relied upon for holding the glaze and slip to the body, can be reduced.

The cost of gum arabic sorts is 18.1 cents *f. o. b.* Auburn. The increase in the cost of a ton of glazed terra cotta is about 18.8 cents; for standard finish, about 9.9 cents.

The souring and fermenting on standing is a bacterial action and tends to destroy the holding quality of the glazes. It can be stopped with formaldehyde, or other disinfectants.

HEAT BALANCE OF A CONTINUOUS TUNNEL KILN[1]

BY CARL B. HARROP, COLUMBUS, OHIO

In Volume XVIII of these Transactions Mr. L. E. Barringer describes a continuous tunnel kiln of the moving car type, which is in successful operation at the plant of the General Electric Co., Schenectady, N. Y.

The first kiln of this design constructed in the United States, was built at a refractories plant at Keasbey, near Perth Amboy, N. J., and was put into operation in June, 1910. At the present time there are two of these kilns in successful operation at this plant.

During the summer of 1916 the U. S. Bureau of Standards conducted a series of tests on kiln designated as No. 1 at the Keasbey plant and the following account covers the first of the series of four tests.

The Kiln. The kiln is 197 feet long, with a tunnel cross section 4 ft. 4 in. wide by 8 ft. high from the top of the track rails to the center of the crown.

Four hand-fired horizontal grate bar furnaces are used, — two on each side of the kiln, located close together and about 108 feet from the charging end. The grate area of each furnace is 16½ in. by 39 in. The ash pits are depressed and are kept filled with water.

The draft outlet from the kiln is located about 18½ feet from the charging end of the kiln. Two vertical flues in the side walls at this point, — one on each side of the tunnel, — drop past fire clay slab dampers into the main draft flue, which runs transversely underneath the kiln. This main draft flue which also serves tunnel kiln No. 2 leads to a chimney 126 feet high by 5 ft. 6 in. diameter inside, the top of which is closed to 5 ft. 6 in. by 15 in.

[1] By permission of the Director of the Bureau of Standards.

The Cars. The cars have a strong steel frame mounted on four single-flanged wheels and carry a clay superstructure or platform 4 ft. 1¼ in. wide by 5 ft. 5 in. long, weighing about 2360 pounds. The iron work weighs approximately 890 pounds.

The cars will carry about 900 standard fire bricks, weighing nearly 3 tons burned.

The Ware. The ware, which is said to be burned to cone 14, is standard size fire bricks and other refractories of various shapes and sizes.

The distribution of heat through the ware seemed to be good, altho no test was made to determine what variations of temperature existed.

Operation of the Kiln. The kiln is operated day and night alike. The tunnel holds 36 cars, — 17 are heating up, 4 are in the high fire zone and 15 are cooling at all times.

At the time of this test a car was taken from the discharge end every two hours; a car of green ware was then run into the lock or vestibule at the charging end and finally the whole train was moved down one car length by means of a geared hand winch, located near the charging end. On some occasions, when burning all brick, the cars are moved at shorter intervals.

It is planned to fire the furnaces immediately after moving the cars, altho sometimes they have to be fired more often, in which case the time of firing does not always correspond with the moving of the cars.

Morgan run-of-mine gas coal, from the Fairmount, W. Va., district was used during the tests and the grates were cleaned twice each 24 hours.

The Testing Apparatus. A small combination and pan scale was used to weigh the coal fired, the ash before and after drying, and the green brick before and after drying.

A Hygrodeik (wet and dry bulb hygrometer) placed near the kiln in a position protected from radiation, was used for determining the temperature of the atmosphere and the humidity, — a 12-inch desk fan supplying continuous air circulation.

Three platinum platinum-rhodium thermo-couples were hung thru the center of the crown into the top of the tunnel (the ends extending about 4 inches below the under surface of the

crown) at the places marked P^1, P^2 and P^3. One copper-constantan thermo-couple was placed in each of the two draft outlets. One portable copper-constantan thermo-couple of No. 30 wire, having the junction placed on a small soft pad on the end of an asbestos rod was used for measuring the temperature of the discharged ware and car and for measuring external kiln temperatures.

A Leeds and Northrup portable potentiometer was used in connection with all thermo-couples.

A Williams gas analysis apparatus was used for determining carbon dioxide, oxygen and carbon monoxide in the combustion gases.

An incline-tube draft gage was used for determining the static draft in the two draft outlets.

A Pitot tube in connection with the draft gage was used for measuring the velocity pressure in the two draft outlets.

The Test. It was planned to obtain such data during the test as would enable one to calculate all or practically all of the various heat expenditures and heat losses which take place in the regular operation of the kiln. The benefit to be derived is twofold. First, it will show by comparison in what respects it is more or less efficient than another type of kiln and second, it will show in what way its own efficiency may be increased.

This test covered a period of 6 hours, — from 10:20 A. M. to 4:20 P. M., during which time the cars were shifted three times, and the furnaces were fired 4 times.

The fires were cleaned at 9:00 A. M. and immediately before the test began the ash pits were filled with water to an observed level.

The temperature and humidity readings were taken every two hours.

At each firing the exact amount of coal charged was noted and a sample preserved in a sealed jar for analysis and determination of calorific value.

As each car was discharged from the kiln, the temperature of the ware and clay in the car structure was taken on both sides at places which seemed to represent the average temperature of the mass. The same procedure was followed in re-

gard to the iron work in the car structure. The number of the car was noted, so that the ware which it carried could be looked up from the records in the burner's office.

Two bricks were taken from the setting of each car of green ware introduced into the kiln, and the number of the car noted. These bricks were weighed and then placed on top of the car which was just discharged. After becoming thoroly dry, they were reweighed, giving by difference the mechanical and hygroscopic water content. The bricks taken as samples in this way during the test were crushed and a sample preserved for determination of chemical water.

At intervals of approximately one hour, the temperature of the flue gases in each draft outlet was noted.

Continuous flue gas samples were taken during the test from each draft outlet, covering the period from just before one fire to just before the next.

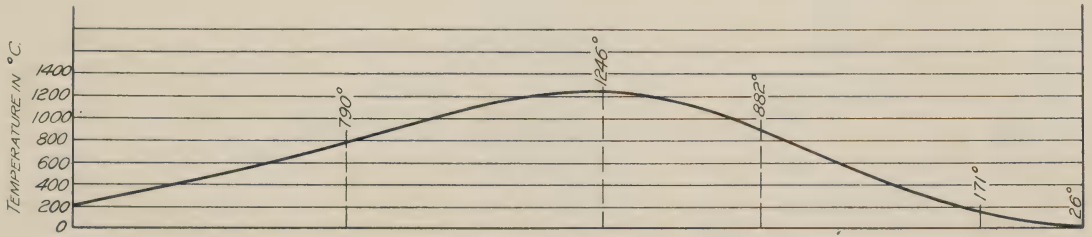
At the end of the test the static draft and also the velocity pressure of the flue gases was determined in each draft outlet, altho no use is made of the data in this calculation.

At intervals of one hour, starting at the beginning of the test, the interior temperatures at points P^1, P^2 and P^3 (Fig. 1) were noted, and at the conclusion of the test the exterior temperatures of the kiln were taken at B^1, C^1, D^1, B^2, C^2, D^2, C^3 and D^3. B^3 was inaccessible.

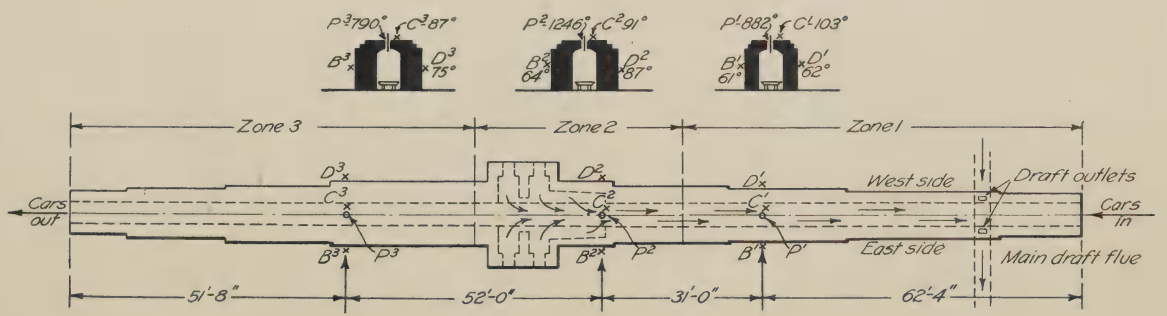
These exterior temperatures might have been taken more often and at more places over the surface of the kiln, but it required considerable time to obtain a set of the eight readings as indicated above, and more time could not be spared from other duties during the test. Also the exterior of the kiln is rather irregular in shape, with numerous local variations in temperature, so that anything like an accurate average of the exterior temperature of the kiln could be obtained only by taking readings at a hundred or more places.

At the conclusion of the test, the ashes were removed from the pits, which were immediately filled with water to the original level and note made of the quantity of water required. Also the ashes were sampled at once, — the sample weighed, then dried on top of the kiln and then reweighed to determine

TRANS AM CER SOC VOL XIX FIG. 1. HARROP



TEMPERATURE CURVE THRU TUNNEL



the water content. The dried ashes were quartered and a smaller sample retained for analysis.

DATA AND CALCULATIONS

Ultimate Analysis of Coal	*percent*	*Proximate Analysis of Coal*	*percent*
Hydrogen	5.22%	Moisture	1.85%
Carbon	76.17	Volatile matter	37.43
Nitrogen	1.50	Fixed carbon	53.18
Oxygen	7.65	Ash	7.54
Sulfur	1.92		
Ash	7.54		
	100.00		100.00

Calorific value ..... 7675 Cal.

The total coal fired during the test was 1937 lbs. or 877 kg.

$877 \times 7675 = 6{,}730{,}975$ large calories total heat possible from coal as supplied.

(1) *Proximate Analysis of Ash*

	percent
Moisture	0.15
Volatile matter	1.65
Fixed carbon	28.66
Ash	69.54
	100.00

877×7.54 percent $= 66.1$ kg. pure ash in coal

$$\frac{66.1}{.6954} = 95.1 \text{ kg. ash as sampled}$$

95.1×28.66 percent $= 27.25$ kg. carbon in ash

$27.25 \times 8.100 = 220.725$ Cal. *lost* in ash from coal supplied.

$$\frac{220{,}725}{6{,}730{,}975} \times 100 = 3.27 \text{ percent loss.}$$

(2)

$877 \times .7617 = 668$ kg. carbon in the coal supplied.
$668 - 27.25 = 640.75$ kg. carbon actually consumed.
The gram-molecular volume of gaseous carbon weighs 12 gms.

$\therefore \frac{640{,}750}{12} = 53{,}396$ gram-molecular volumes of gaseous carbon from the coal.

The average of the analyses of combustion gases shows 3.29 percent. CO_2 and 0.16 percent CO, or a total of 3.45 percent of carbon bearing gases.

$\therefore \frac{53{,}396}{.0345} = 1{,}547{,}710$ gram-molecular volumes or total volume (at O°C) of the dry flue gases from the coal consumed (and excess air).

The average of the analyses of combustion gases was:

CO_2	3.29	percent
O_2	16.67	
CO	0.16	
N_2	79.88	(by difference)
	100.00	

Then

$.0329 \times 44 =$	1.45
$.1667 \times 32 =$	5.33
$.0016 \times 28 =$	0.045
$.7988 \times 28 =$	22.365
	29.19 gms. = weight of one gram-molecular volume of the dry flue gases at O° C. and

$1{,}547{,}710 \times 29.19 = 45.178$ kg. = total weight of dry flue gases.

The average temperature of the atmosphere was 26.2°C. And the average temperature of the flue gases was 171°C. The mean temperature is 98.6°.

Using the formulae given below, the specific heats of the constituent gases at the mean temperature will be:

$$CO_2 \ldots 0.193 + 168 \times 10^{-6}\ t = 0.2095$$
$$O_2 \ldots 0.213 + 38 \times 10^{-6}\ t = 0.2167$$
$$N_2 \text{ and } CO \ldots 0.243 + 42 \times 10^{-6}\ t = 0.2471$$

Then from the weight composition of the flue gases, as noted above, the specific heat of these gases can be calculated as follows:

CO_2	1.45	= .0497	× .2095 = .01041
O_2	5.33	= .1828	× .2167 = .03961
CO	0.045	= .0015	
N_2	22.365	= .7660	× .2471 = .18965
	29.19		0.23967 = Sp. heat of dry flue gases at the mean temperature.

$45{,}178 \times (171 - 26.2) \times 0.2397 = 1{,}568{,}039$ *Cal.* = heat in excess of atmospheric temperature leaving the kiln in the dry flue gases.

$$\frac{1{,}568{,}039}{6{,}730{,}975} \times 100 = 23.3 \text{ percent loss.}$$

(3)

Calculation (2) shows 1,547,710 gram-molecular volumes of dry flue gases (at o° C).

$1{,}547{,}710 \times .7988 = 1{,}236{,}311$ gram-molecular volumes of nitrogen in the flue gases (at o°C).

$$\frac{1{,}236{,}311}{.792} = 1{,}560{,}997 \text{ gram-molecular volumes of dry air}$$

drawn into the kiln.

$$\text{Then } \frac{1{,}560{,}997 \times 22.3}{1000} = 34{,}810 \text{ cu. m. of dry air at o°C.}$$

34,810 cu. m. of dry air at o° C : 273 :: x : 299.2
x = 38,151 cu. m. dry air at 26.2°C.

The barometric pressure during the test was 760 m. m. of mercury.

The vapor pressure of completely saturated atmosphere at 26.2°C is 25.5 m. m. of mercury.

The average relative humidity of the atmosphere during the test was 33.8 percent.

The average partial pressure of the atmosphere due to the moisture was $25.5 \times .338$ or 8.48 m. m. of mercury.

$760 - 8.48 = 751.52$ m. m. partial pressure due to the dry air

$$38{,}151 \times \frac{760}{751.52} = 38{,}581 \text{ cu. m. of moist atmosphere at } 26.2°\text{C.}$$

The actual humidity of the atmosphere corresponding to a relative humidity of 33.8 percent, 26.2° temperature and 760 m. m. barometric pressure is 8.18 gms. water vapor per cu. m. of atmosphere.

$\therefore$ $38{,}581 \times 8.18 = 315.7$ kg. water vapor entering the kiln with the dry air. This water vapor was raised in temperature from 26.2° to 171°C.

The specific heat of water vapor at the mean temperature

$$\text{between } 26.2° \text{ and } 171° = 0.447 + \frac{324 \times 98.6}{1{,}000{,}000} = 0.48$$

Then $315.7 \times (171 - 26.2) \times 0.48 = 21{,}942$ *Cal.* in the moisture of the atmosphere passing out with the flue gases.

$$\frac{21{,}942}{6{,}730{,}975} \times 100 = 0.33 \textit{ percent loss.}$$

(4)

From calculation (1), there were 95.1 kg. of ash in the ash pits at the end of the test.

4.735 kg. of this wet ash weighed after being dried 2.71 kg.

$\therefore$ $4.735 : 2.71 :: x : 95.1$, $x = 166$ kg. ash and water removed from the ash pits, and $166 - 95.1 = 70.9$ kg. water removed with the ash at the end of the test.

It required 257 kg. water to fill the ash pits to the same level as when the test started.

$\therefore 257 - 70.9 = 186.1$ kg. water was evaporated from the 4 ash pits during the test.

To calculate the heat used in evaporating this water and also that which was carried out in the vapor with the flue gases, it can be assumed that the water was at the temperature of the atmosphere when introduced and that the evaporation took place at 100° C.

The total heat required can then be summed up as follows:

Sensible heat of water (26.2° to 100°: $186.1 \times 73.8 = 13.734$ Cal.

Latent heat of vaporization: $186.1 \times 537 = 99{,}936$ Cal.

To raise water vapor from 100° to 171: $186.1 \times 71 \times 0.491$[1] 6,488 Cal.

Total ..... *120,158 Cal.*

$$\frac{120.158}{6{,}730.975} \times 100 = 1.79 \text{ percent loss.}$$

(5)

From calculation (6), the average weight of dry green ware per car was 2754 kg.

From determinations made during the test, the average amount of mechanical and hygroscopic water in the ware as charged into the kiln was 4.5 percent.

$$\therefore \quad \frac{2754}{1.0 - .0455} = 2882 \text{ kg.} - \text{weight per car of green ware as charged,}$$

and $2882 - 2754 = 128$ kg. mechanical and hygroscopic water per car or $128 \times 3 = 384$ kg. mechanical and hygroscopic water driven off during the test.

[1] Specific heat of water vapor at the mean temperature between 100° and 171° C. $= 0.447 + \frac{324 \times 135.5}{1{,}000{,}000} = 0.491.$

Assuming the ware contained 1 percent hygroscopic water, there would be (4.5 percent — 1 percent) 3.5 percent mechanical water.

and $\frac{3.5}{4.5} \times 384 = 298.7$ kg. mechanical water driven off during the test.

$298.7 \times (100 - 26.2$	= 22,044 cal. sensible heat in water.
$298.7 =$ 537	= 160,402 cal. latent heat of vaporization.
$298.7 \times (171 - 100) \times .491$[2]	= 10,413 cal. sensible heat above 100° C in vapor.
Total heat in mechanical water	= 192,859 Cal.

$\frac{1}{4.5} \times 384 = 85.3$ kg. hygroscopic water driven off during the test.

Taking the mean temperature at which the hygroscopic water is driven off as 200° C.

$85.3 \times (200 - 26.2)$	= 14,825 Cal. sensible heat in water.
85.3×477[3]	= 40,688 Cal. latent heat of vaporization.
	55,513 Cal. total heat.

On cooling from 200° to 171° C, the following heat is given up by the water vapor:

$$85.3 \times 29 \times .507^{4} = 1254 \text{ Cal.}$$

Then 55,513 — 1254 = 54,259 Cal. net amount of heat used in evaporating the hygroscopic water during the test and passing out with same.

---

[2] Specific heat of water vapor at the mean temperature between 100° and 171° C. See calculation 4.

[3] Latent heat of water vapor at 200° C. from formula 596 — 0.60 t (Griffith).

[4] Specific heat of water vapor at the mean temperature between 171° and 200° C.

$$0.447 + \frac{324 \times 185.5}{1{,}000{,}000} = .507.$$

192,859 + 54,259 = *247,118 Cal.* total heat chargeable to the mechanical and hygroscopic water.

$$\frac{54,259}{6,730,975} \times 100 = 3.67 \text{ } \textit{percent loss.}$$

(6)

The average weight of ware on the cars charged and discharged during the test was 2629 kg. per car on burned basis.

From laboratory determination, the content of chemical water in the unburned clay was 4.55 percent.

$$\therefore \quad \frac{2629}{1.0 - .0455} = 2754 \text{ kg., weight of dry green ware on one car and}$$

2754 — 2629 = 125 kg. chemical water per car
or 125 x 3 = 375 kg. chemical water driven off during the test.

From determinations made by Brown and Montgomery,[5] the temperature of the maximum rate of dehydration of fire clays will run about 560° C. Taking the specific heat of green clay as 0.2,

375 × (560 — 26.2) × 0.2 = 40,035 Cal. sensible heat in chemical water
375 × 609[6] = 228,375 Cal. heat of dehydration
375 × 261[7] = 97,875 Cal. latent heat of vaporization
366,285 Cal. Total.

On cooling from 560° to 171° C, the following heat will be given up:

$$375 \times 389 \times 0.565^{8} = 82,419 \text{ Cal.}$$

[5] Technical Paper No. 21, Bureau of Standards.
[6] Calculated from values given in Richard's "Metallurgical Calculations."
[7] Latent heat of water vapor at 560° C. from formula — L = 596.73 — 0.60 t (Griffith).
[8] Specific heat of water vapor at the mean temperature between 171° and 560° C.

$$0.447 + \frac{324 \times 365.5}{1,000,000} = 0.565.$$

Then 366,285 — 82,419 = *283,866 Cal.* net amount of heat used in dehydrating the clay and passing out with the vaporized chemical water.

$$\frac{283,866}{6,730,975} \times 100 = 4.22 \text{ percent loss.}$$

(7)

From calculation (2), the weight of CO in 1 gram-molecular volume of dry flue gases (at O°C) was 0.045 gms.

Then, as there were 1,547,710 gram-molecular volumes of dry flue gases produced during the test,

1,547,710 × 0.045 = 69.65 kg. CO escaped in the flue gases.

Taking the heat of combustion of CO as 2436 Cal. per kg. of CO, 69.65 × 2436 = *169,667 Cal.* heat represented in the unconsumed CO in the flue gases.

$$\frac{169,667}{6,730,975} \times 100 = 2.52 \text{ percent loss.}$$

(8)

The weight of ware and the clay structure on the three cars discharged during the test, together with the average temperature of the mass on each car was as follows:

Car No. 126 { Ware.....2827 kg.
Structure 1073.5 kg.
Total...3900.5 kg. × 465.8° × 0.23[9] = 417,877 Cal.

Car No. 10 { Ware.....2470 kg.
Saructure 1073.5 kg.
Total...3543.5 kg. × 441.8° × 0.23 = 360,069 Cal.

Car No. 38 { Ware.....2460 kg.
Structure 1073.5 kg.
Total...3533.5 kg. × 456.8° × 0.23 = 371,244 Cal.

Total ..... 1,149,190 Cal.

[9] Specific heat of burned clay.

discharged during the test in ware and clay in car structure.

$$\frac{1,149,190}{6,730,975} \times 100 = 17.07 \text{ percent loss.}$$

(9)

The average weight of the ironwork in the car structure was 404.5 kg. This with the average temperature of the ironwork in each car at the time of discharging from kiln and the latent heat of iron (taken as 0.12) will give the following:

Car No. 10	$404.5 \times 110.8° \times 0.12 =$	5,378 Cal.
Car No. 126	$404.5 \times 81.8° \times 0.12 =$	3,971 Cal.
Car No. 38	$404.5 \times 83.8° \times 0.12 =$	4,068 Cal.
Total		13,417 Cal.

discharged during the test in the ironwork of the cars.

$$\frac{13,417}{6,730,975} \times 100 = 0.2 \text{ percent loss.}$$

(10)

Exterior temperature readings of the kiln structure were taken on the sides and crown at three different places throughout the length of the kiln.

In this attempt to roughly calculate the radiation and convection loss, the temperatures at B^1, C^1 and D^1, were considered as being the average from the charging end of the kiln up to a point half way between where these temperatures were taken and the point where temperatures B^2, C^2 and D^2 were taken. This area, indicated in Fig. 1, is designated as Zone 1. Zones 2 and 3 were laid out in a similar way.

Assuming that the average temperature of the two sides at B^1 and D^1 is the average temperature of the side walls of the kiln throughout Zone 1 and that the temperature at C^1 is the average temperature of the top of the kiln throughout Zone 1, and taking the mean outside width of the kiln as 10 ft. and the mean height of the kiln above the ground as 10 ft., the average temperature of the entire exterior of the kiln can be approximated:

Zone 1	Sides	1560 sq. ft.	÷ 5910 = .264	× 61.5°	= 16.23
	Top	780 sq. ft.	÷ 5910 = .132	× 103.	= 13.40
Zone 2	Sides	820 sq. ft.	÷ 5910 = .139	× 75.5	= 10.50
	Top	410 sq. ft.	÷ 5910 = .069	× 91.	= 6.28
Zone 3	Sides	1560 sq. ft.	÷ 5910 = .264	× 75.	= 19.80
	Top	780 sq. ft.	÷ 5910 = .132	× 87.	= 11.50
	Total	5910 sq. ft.			77.71°

or 78° = Average Temperature.

5910 sq. ft. = 549 sq. m.

Radiation and convection in small calories per sq. metre of surface per hour = $(124.72K)(1.0077^{t})(1.0077^{T} - 1)$[10] = 920,000 small Cal.

549 × 920,000 = 505,000 large Cal. per hour and 505,000 × 6 = *3,030,000 Cal.* lost by radiation and convection during the 6 hour test.

$$\frac{3{,}030{,}000}{6{,}730{,}975} \times 100 = 45 \text{ } \textit{percent loss.}$$

In addition to knowing the percentage of heat leaving the kiln at the discharge end, it would also be interesting to know what the *excess* heat leaving at this point is capable of doing in drying the ware.

The average temperature of the discharged clay ware during the test was 481° C and the ironwork of the cars 119° C.

If the temperature of the ware and the clay in the car structure could have been reduced to say 100° C at the discharge end and also the temperature of the car ironwork reduced proportionately, the heat available for drying purposes would have been:

10,978 kg.	× 381°	× .23	= 962,000
1,214	× 78	× .12	= 11,363
Total			973,363 Cal.

If the ware contained 20 percent mechanical water, when molded there would be $\left\{\frac{2754}{80} - 2754\right\} \times 3$ or 2064 kg. mechanical water represented in the ware produced during the test.

[10] Péclet. K, a constant, which for brick is 3.6. t is temperature of surrounding atmosphere. T is temperature of the radiating surface.

Assuming a drier of the tunnel type in which the mean temperature of evaporation is, say 65° C, with atmospheric temperature 20°C, the heat necessary to dry this ware will be approximately:

$3 \times 2754 \times (65 - 20) \times 0.2 =$	74,340	Cal.	sensible heat in clay
$2064 \times (65 - 20) =$	93,000	Cal.	sensible heat in water
$2064 \times 561 =$	1,159,000	Cal.	latent heat of vaporization
Total	1,326,340	Cal.	

If the vapor cools from 65° to 45° C before emerging from the drier, the heat given back (or left in the drier) will be:

$$2064 \times (65 - 45) \times .465^{11} = 19{,}195 \text{ Cal.}$$

Then 1,326,340 — 19,195 = 1,307,145 Cal. Total heat necessary to dry, at a drier efficiency of 100 percent.

If the tunnel drier were working at an efficiency of 67 percent, *i. e.* a total heat requirement of 1,946,726 Cal., this heat from the discharge end of the kiln alone would be about one-half enough to dry completely the amount of ware discharged during the test.

The average excess of air leaving the kiln in the flue gases during the test was 352 percent and accounts in a large measure for their comparatively low average temperature of 171°C.

If it were possible to operate the kiln with only 100 percent excess of air, — the temperature of the gases remaining the same, — there would have been a saving in the dry excess air of

$$\frac{252}{452} \times 1{,}560{,}997 \times 28.83^{12} \times (171 - 26.2) \times .24 = 873{,}000 \text{ Cal.}$$

To this should be added $\frac{252}{452}$ of the heat calculated under

[11] Specific heat of water vapor at the mean temperature between 45° and 65° C.

$$.447 + \frac{324 \times 55}{1{,}000{,}000} = .465$$

[12] Weight of one gram-molecular volume of dry air at 0° C.

(3) as passing out of the kiln in the moisture of the excess air with the flue gases.

$$i.\ e.\ \frac{252}{452} \times 21{,}942 = 12{,}220 \text{ Cal.}$$

Therefore, it would seem that the sum, — 885,220 Cal. or 13.3 percent of the fuel could have been saved, if the excess air had been reduced to 100 percent.

However, if the greater part of this excess air comes thru the combustion zone of the kiln, a lowering of the amount would result in a slower velocity, a larger extraction of the heat and therefore a lowering of the stack temperature, which would hardly seem permissible.

On the other hand, if a large part of this excess air enters (as seems very probable) at the charging end of the kiln, particularly around the car moving mechanism, a reduction of the amount of air leakage, would result in a higher stack temperature, but would show no saving in fuel.

Some idea may be gained of the source of this excess air by allowing, say 100 percent excess thru the grates and adding the amount of air necessary to cool the ware and cars between the combustion zone and the discharge end of the kiln.

Assume that the temperature of the ware after passing thru the combustion zone were 1350°C and that it cooled to an average of 481°C at the discharge end.

After a deduction of say 40 percent for radiation loss, the amount of heat to be carried back towards the combustion zone during the test would have been

$$10{,}978 \text{ kg.} \times (1350° - 481°) \times 0.23 \times 0.6 = 1{,}315{,}000 \text{ Cal.}$$

If, during this cooling of the ware and cars, the air passing in at the discharge end of the kiln, were raised in temperature from that of the atmosphere (26.2°C) to say 1000°C by the time it reached the combustion zone, the amount of the air[13] necessary to carry this heat would have been

[13] In this calculation the moisture in the air has been neglected, since the heat carried out by it at the stack temperature would be only a little over 1 percent of the heat carried out by the accompanying dry air.

FIG. 2.

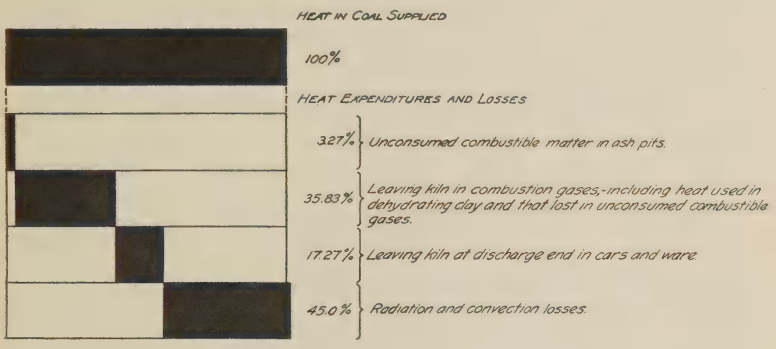
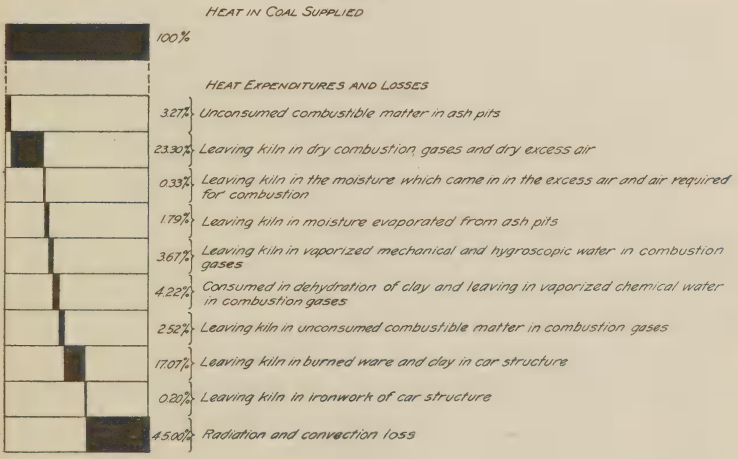

HEAT IN COAL SUPPLIED
100%
HEAT EXPENDITURES AND LOSSES
3.27% Unconsumed combustible matter in ash pits.
35.83% Leaving kiln in combustion gases,-including heat used in dehydrating clay and that lost in unconsumed combustible gases.
17.27% Leaving kiln at discharge end in cars and ware.
45.0% Radiation and convection losses.

FIG. 3.


HEAT IN COAL SUPPLIED
100%
HEAT EXPENDITURES AND LOSSES
3.27% Unconsumed combustible matter in ash pits
23.30% Leaving kiln in dry combustion gases and dry excess air
0.33% Leaving kiln in the moisture which came in in the excess air and air required for combustion
1.79% Leaving kiln in moisture evaporated from ash pits
3.67% Leaving kiln in vaporized mechanical and hygroscopic water in combustion gases
4.22% Consumed in dehydration of clay and leaving in vaporized chemical water in combustion gases
2.52% Leaving kiln in unconsumed combustible matter in combustion gases
17.07% Leaving kiln in burned ware and clay in car structure
0.20% Leaving kiln in ironwork of car structure
45.00% Radiation and convection loss

$x \times 1000° - 26.2°) \times 0.27$[14] $= 1{,}315{,}000$ Cal.
$x = 4{,}900$ kg. dry air.

$\frac{4{,}900{,}000}{28.83} = 170{,}00$ gram-molecular volumes of dry air at O°C.

or $\frac{170{,}000 \times 23.3}{1000} = 3790$ cu. m. dry air at O°C.

From calculation (3), the total volume of dry air entering the kiln (reduced to O°C) was 34,810 cu. m. representing 452 percent.

Therefore 3790 cu. m. represents $\frac{3790}{34{,}810} \times 452$ percent or 49.2 percent air, which, together with the 200 percent passing through the grates would make 249 percent passing through the combustion zone of the kiln and indicate that 452 percent — 249 percent or 203 percent of air was leaking in at the charging end of the kiln, diluting and lowering the temperature of the flue gases.

It will be noted that there is an expenditure of 1.79 percent of the total heat in evaporating water from the ash pits and the justification of the use of this water may be questioned.

The vapor from this water in passing thru the grates eliminates an equivalent volume of air, which would otherwise pass thru. This water vapor carries out of the kiln about one-third more heat than the same volume of air would carry but as the amount of heat involved is small, the loss directly chargeable to the water over and above the loss in the same volume of air would be an almost negligible quantity.

Furthermore, from the practical standpoint, the grates are kept cooler and there is less tendency for clinkers to form on the grate bars. Elimination of this trouble undoubtedly justifies the heat loss incident to the use of this water.

The radiation loss, stated in percentage of total heat evolved, seems surprisingly large, but when it is taken into account that the weight of coal used in proportion to the weight of ware pro-

[14] Specific heat of dry air at the mean temperature between 1000° and 26.2° C.

duced is small, the actual loss through radiation is not such a large item.

The explanation of the seemingly high percentage loss by radiation lies in the fact that the ware is not massed but is strung out in a long slender line, and therefore the amount of exterior kiln surface per unit weight of ware is much larger than in the case of a periodic kiln.

At the time of the test the kiln was operating with a capacity of 10 7/10 thousand standard fire brick per 24 hours.

The weight of coal supplied compared with the average of the weights of ware charged and discharged during the test, shows a fuel consumption of 11.15 percent, or per thousand standard fire brick — 725 lbs. of coal.

In conclusion, it should be stated that the test was undoubtedly of too short duration to give absolutely reliable data on the average performance of the kiln. A test of this kind should properly be carried on continuously for a period of from one week to ten days.

DISCUSSION

Mr. Washburn: In addition to the heat required for the evaporation of the water from the ware, a certain amount is involved in the other physical and chemical changes which take place at high temperatures, and I would like to ask under which one of the items this heat would be found?

Mr. Harrop: That point was taken into consideration, but so far as we knew, there is no reliable information, and no definite way that we could get at it. Of course we know that there is heat given up by the decompositon of certain minerals and that there is heat required in the formation of certain new compounds but the net difference was believed to be such a comparatively small item that it could be neglected in such a test as this.

DISCUSSION CONTRIBUTED AFTER READING THE PAPER

Mr. Lovejoy: This work of Prof. Harrop is in an important field of the ceramic industries, — the most important because it involves the greatest item of cost of the product and the success

of any ceramic industry depends largely upon the results and economy of the burning.

Bleininger's tests of "Four Industrial Kilns" several years ago gave us some definite information and the clay workers' appreciation of this work is evidenced by the frequent quotations of the data presented. It led to several tests of individual operations, and a continuation of the work will eventually lead to wide spread individual tests with their attendant beneficial results. It will enable us to intelligently compare different types of kilns, and to select the best of any particular purpose.

Although the test in question lasted but six hours it pointed out the loss in heat from the cooling ware after leaving the kiln, — a loss equal to one half the fuel cost of drying the ware. We usually reckon that the drying requirement is 100 pounds of coal per ton of ware, and there is a possible saving of 50 pounds per ton in the operation in question. The capacity of the two kilns on the yard where the test was made is about 70 tons per day, and the recovery of this waste heat means a saving of 1¾ tons of coal per day, — a saving not to be despised. The large excess air content gives opportunity for further fuel reduction, and if the operators take heed of the results of the test they can effect a material economy in the fuel.

I cannot agree with Prof. Harrop that there is no fuel loss if the air enters through the charging door. Any fuel that can be saved becomes a loss if it is not saved. The excess air, whether it comes through the combustion zone or the charging door, requires heat which might be put to some useful purpose. The stack intensity would be increased by the higher temperature available if there were no excess air and would be further increased by the decreased volume of gases to be moved. This would serve to increase the rate of combustion and in consequence the rate of progress through the kiln. Although the two might balance and the fuel consumption per ton of ware remain the same, yet the ware would leave the kiln at a higher temperature and the heat would be useful for drying purposes. If this were not practical, the kiln, at least in a new installation, could be made longer and the heat now used in heating and moving a dead

load of air could be applied to the ware with a direct saving in the fuel requirement.

Prof. Harrop expresses the doubt, whether, if the excess air was eliminated, assuming that it comes through the combustion zone, there might not be danger of reducing the chimney temperature below a permissible degree in consequence of the decreased volume of gases and the slower movement through the kiln.

It may be mentioned that, —

(1) The smaller volume would have a higher initial temperature and correspondingly greater heat value to offset the slower movement.

(2) Carbon-dioxide has an average higher thermal capacity than air, and the movement could be reduced proportionately without effect on the relative temperature.

(3) The heat required for the excess air would be available to maintain the temperature requisite for draft.

If, with these gains, the temperature becomes too low to maintain the proper draft, the kiln should be shortened and not loaded with excess air to maintain a faulty kiln condition.

I mentioned the possible need of lengthening the kiln, and now propose to shorten it, to overcome a loss. The kiln as it stands may be the mean between a needed longer kiln and a required shorter one, but whatever the proper length the loss due to excess air should be materially eliminated.

I do not find that Prof. Harrop has included in his calculations the moisture from the coal nor the much larger volume of moisture which would be developed from the hydrogen. This I figure to be .48 percent. No account is taken of the sulphur in the coal, and Prof. Harrop has called my attention to another small omission; namely, that the nitrogen in the coal should have been deducted from the total nitrogen from which the air is determined. These are all small items and do not materially affect the final results.

I object to the use of a formula for the radiation losses. Prof. Harrop and I have discussed this formula question and I think we agree that very little reliance could be placed on any formula for such widely varying conditions as prevail in kiln radiation losses. All of us who have occasion to use such for-

mulas, are guilty of selecting that which most nearly checks our results or confirms our conclusions. The formula in question, which is from good authority, checks up the loss by difference within one percent, but this is merely a coincident, and if Prof. Harrop had made a suitable allowance for the heat conducted into the ground from the kiln walls, he probably would not have used this particular formula, — probably no formula whatever, — but would have given the radiation loss by difference. The use of the formula establishes a precedent, and it should apply to all kiln radiation loss determinations which it likely will not do. If subsequent test show that it does check up the loss by difference within a reasonable degree, then I am wrong, and the formula should become a part of our kiln heat determinations, and could be used independent of the other factors in the test.

Forty-five percent radiation loss seems a large item, but it undoubtedly is very near the truth. In pounds of coal (93 pounds) per ton of ware it does not look so large.

Bleininger's tests gave 54.9 percent radiation and kiln wall absorption loss for a paving brick periodic kiln and 49.61 percent for a sewer brick kiln, and the weights of coal per ton of ware were 329 pounds and 232 pounds respectively. The temperatures of the periodic kilns were very low compared with that of the kiln in question, and higher temperatures would have materially increased the radiation losses.

A test, or a calculation, of a German continuous kiln some years ago gave the radiation loss as 32 percent.

Alexandre Bigot, in Vol. XV, Trans. English Ceramic Society gave data for three types of kilns, — the Dressler, the Hoffman, and a periodic kiln, which reduced to 100 percent is as follows: —

Dressler kiln, —

Chimney loss	8.3 percent.
Evap. of water	8.5
Firing the ware	49.6
Supports and trucks	19.1
Gasification and radiation loss	5.4
In cooling ware	9.1
	100.0

Hoffman kiln, —

Chimney loss	6.9	percent.
Evaporation of water	3.8	
Firing the ware	22.9	
Excess air	34.4	
Heat in the walls	25.2	
Radiation	6.9	
		100.1

Periodic kiln, —

Chimney loss	42.1	percent.
Chemical water	2.5	
Firing the ware	15.0	
Excess air	34.4	
Loss through ground and air	9.0	
To heat walls	20.1	
		100.0

Unfortunately Bigot does not tell us how the data was obtained, and a study of it leads one to the conclusion that it may be partly compilation from actual tests and partly assumption, and comparatively of little value. There is too much of this kind of questionable data.

It seems to me that it would be a good plan to adopt some standard for the summation of the results of the tests in order to compare them with other results. The average clay worker is not interested in the details of the test but desires to see the results in a form which he can readily understand and appreciate.

I would suggest, —
Chimney losses.
Carbon in the ash.
Firing the ware including evaporation and dissociation.
Excess air.
Radiation including ground and kiln absorption.
Kiln trucks and supports.
Producer losses.
Temperature.
Duration of the burning period.
Heat value of the coal.

A kiln heat balance is a difficult problem involving, as it does, numerous factors and largely dependent on gas analyses, which at best are only approximations of the actual composition of the gas. The firing operations are intermittent, and the composition of the gas varies from minute to minute. The samples of gas are taken at intervals, and to get any reliable average a great many samples must be taken which could not be done in this test. A continuous sampling equipment should be developed for the work and each sample then would cover the full period between the successive analyses. The total error in a test of this kind may exceed 10 percent and the final tabulation should collect the results under a few general heads in which the permissible errors will tend to balance each other.

The car tunnel kiln has been on the way for many years but up to the present time only three so far as I know have met with any promise of success in this country; namely, the Faugeron kiln in question, the Dressler kiln, and one other still in the experimental stage. We know too little about them to judge of their merits in comparison with other types of continuous kilns, and it is to be hoped that the work of testing the kilns will be continued until sufficient data has been collected for comparison. Following that, or meanwhile, the clay workers will be studying the kilns to determine their mechanical fitness for the several lines of wares.

The fuel consumption as given by the test is 725 pounds of coal per thousand fire bricks or 207 pounds per ton of ware, and the temperature attained is said to be cone 14. It is to be regretted that the temperature was not actually determined. I determined by calculation, assuming that all the air came through the combustion zone and attained a temperature of 1000 degrees C., that it would be barely possible to get a flame temperature of cone 14. I made no allowance for radiation losses which would lower the possible temperature, but on the other hand the air may attain a higher temperature than 1000 degrees and undoubtedly only part of the air comes through the combustion zone, which would make a still higher temperature possible. I made this calculation because high temperatures are frequently claimed which cannot be substantiated by the facts, and I think

we should check up such claims as far as possible rather than put our stamp of approval upon them by failure to question them.

The ring and chambered continuous kilns largely used in this country, so far as I know do not burn wares to as high a temperature as cone 14 and direct comparison of the fuel consumption cannot be made, but judging from the fuel used for lower temperatures, the consumption in the kiln in question is not remarkable.

Compared with periodic kilns where at least three times the quantity of fuel given would be required per ton of similar ware, the showing is an excellent one.

We know that the periodic kiln is wasteful in fuel, and only its adaptability to a wide range of ware maintains its strong hold in the ceramic industries.

The Faugeron kiln must meet the competition of other types of continuous kilns, and its extended use will depend upon other features than the fuel consumption, — such as initial cost, labor to operate, upkeep, results.

The kiln as constructed and operated for the ware in question would not be adapted to a number of clay products. Twelve cars per 24 hours are taken from the kiln, and since the burning zone is 19 car lengths from the charging end, the water-smoking, oxidation, and heating up to the maximum temperature must be done within a period of 38 hours. This would be too short a period for many dry-pressed bricks and a number of carbonaceous clay products. Undoubtedly the kiln could be built longer or operated at a slower rate, to give the necessary time.

As I understand the operation of the kiln the ware must be set to closely conform to the restricted sections of the tunnel. This would be a difficult problem in drain tile ranging from 4 inch to 24 inch, but this could be overcome by the use of a special diaphragm car as in the Drayton kiln, and I think one other. The small sizes of tile would have to be set staggered and in outline would be the frustrum of a pryamid, in order to have any degree of stability, and the cars would have to be carefully handled to prevent toppling of the ware. Large sizes would

have to be set one above the other in order to prevent kiln marking and cracking.

These difficulties and others occur to me and I present them interrogatively. No doubt the representatives of the kiln have devised ways of adapting the kiln to a wide range of wares, and the clay workers of the country would appreciate a general presentation of the possibilities of the kiln.

Some features of the car tunnel kiln are appealing which accounts for the several attempts to develop a satisfactory kiln. It is centrally fired and the kiln in question direct coal fired which brings the firing operation to one or two points. Since the intense heat zone is in a short section of the kiln it may be built of the best quality of fire bricks without excessive cost. The relatively low walls and narrow crown insure a stability which is not possible in the other types of continuous kilns.

On the other hand it must be operated continuously, day, night and holidays, in greater degree than other types of continuous kilns. The chambered continuous kiln is intermittent approximately in 48 hour periods while the regular operation of this kiln is two hour periods. Each period can of course be extended to cover unavoidable delays but the extension would be proportional to the regular operation.

I have wandered from the question, — a discussion of Prof. Harrop's test, but his ability and well known thoroughness in whatever he undertakes does not give one much opportunity to present a different view.

I hope this is only the beginning of such work and that it will continue until all types of kilns have been tested. We will then be in a position to determine the fuel merits of the several kilns and it will be up to the kiln people to prove to us the mechanical merits and the adaptability.

To avoid confusion I think the title of the paper should be changed, and the Society should adopt titles to distinguish the several types of continuous kilns. The chambered (or compartment), kiln, the ring kiln, the zig-zag kiln, and the tunnel kiln are the German designations which leaves no one in doubt as to the type of kiln when the proper name is applied. Since the ring kiln is not built in a ring in this country and the name of

tunnel kiln is generally used to designate it, we might adopt the terms, — chambered kiln, tunnel kiln, and car tunnel kiln.

Mr. Staley: The presentation of the data by the author is, in the main, admirable. I wish to call attention to a couple of minor points in the calculations. The calculation of the amount of heat used in evaporating water and carried out the stack by the steam generated is unnecessarily complicated. In brief, the authors method of calculation consists of the following steps: —

(1). Calculation of heat necessary to raise water to an assumed temperature of vaporization.

(2). Calculation of latent heat of vaporization of water at the assumed temperature.

(3). Calculation of amount of heat used in vaporizing the water.

(4). Calculation of specific heat of steam for the temperature interval through which it is to be heated or cooled.

(5). Calculation of amount of heat used in heating the vapor or given off by the vapor in passing through the given temperature interval.

For the water in the ash pit and mechanical water in the ware, he assumed a temperature of vaporization of 100°C.; for the hygroscopic water in the ware, a vaporization temperature of 200°C; for the chemically combined water, a temperature of 560°C. Thus steps 1, 2 and 4 had to be calculated three times and steps 3 and 5 four times.

It is a fundamental principle of thermodynamics, that the amount of heat involved in transforming a given mass of a substance from a given state and temperature to another given state and temperature, is always the same no difference what the intervening steps may be. To be concrete, for every kilogram of free water entering the kiln at 26.2°C. and leaving as vapor at 171°C. a certain fixed amount of heat is consumed, no difference whether the water is vaporized at 100°C., and the vapor heated at 171°C., or whether the water is evaporated at 200°C. or 560°C. and the vapor cooled to 171°C. Furthermore the same amount of heat would be used if the water were heated to 171°C. and vaporized at that temperature.

By assuming that all four of these classes of water were vaporized at 171°C., the exit temperature of the vapor, it is possible to eleminate the authors steps 4 and 5 altogether, to perform step 2 once, instead of three times, and to combine steps 1 and 3 into one operation.

Using the author's formula, the latent heat of vaporization of water at 171° is derived as follows: —

$$L = 596.73 - 0.60 \times 171 = 494.13 \text{ Cal.}$$

The sensible heat of water heated from 26.2°C. to 171°C. is 171-26.2 = 144.8 Cal.

494.13 + 144.8 = 639 ± Calories for heating and vaporizing 1 kilogram of free water.

Then

186.1 × 639 = 118,918 Cal. heat for water in ash pits.
298.7 × 639 = 190,869 Cal. heat for mechanical water.
85.3 × 639 = 54,507 Cal. heat for hydroscopic water.

. These values are a little lower than those of Professor Harrop, probably due to the use of a value for specific heat of steam in his calculations that differed from the one used in deriving the formula for latent heat of vaporization taken from Griffith.

The thermo-chemical data given in the tables of Richard's *"Metallurgical Calculations"* are for reactions beginning and ending at 15°C[1]. To the heat of dehydration obtained from this data, must be added the heat necessary to convert the water at 15°C. to vapor at 171°C.

If we assume as before that the vaporization takes place at 171°C., the sensible heat necessary to raise the water from 15°C. to 171°C will be 171-15 = 156 Calories per kilogram. From this we may subtract the heat given off by the chemical combined water in solid form in cooling from 26.2°C. to 15°. Taking a specific heat of 0.2 this gives us 0.2 (26.2 — 15) = 4.4 Calories and 156 — 4.4 = 151.6 Calories per kilogram to be supplied for sensible heat.

We have already determined that the latent heat of vaporization of water at 171°C. is 494.13 Cal. By reference to Richards text we find that the authors figure 609 Calories is correct for

[1] See page 15, second edition, of Richards text.

the heat of dehydration of kaolin for the reaction beginning and ending at 15°C.

We have then: —

375×609 = 228,375 Cal. heat of dehydration.

$375 \times (494.13 + 151.6)$ = 242,149 Cal. sensible and latent heat of water.

470,524 Cal. total heat for chemical water.

It would be possible by a complicated calculation to determine the actual heat of dehydration of kaolin starting with the clay at 560° and ending with the products at the same temperature. This value would be much higher than 609 Calories per kilogram of water, and the final value for the total amount of heat used for chemical water would be approximately as I have calculated it above.

BALZ DISCUSSION.

Mr. Balz: I have read with a great deal of interest Professor Harrop's paper on the "Heat Balance of the Continuous Tunnel Kiln," and am of the opinion that the results should be of great interest to the Society, especially as the various data were determined in a very careful manner. My association with the company, at whose works the tunnel kiln tested by Professor Harrop is in operation, gave me an opportunity of following the Professor's work in considerable detail.

It should be borne in mind that the kiln tested by Professor Harrop has been in almost continuous operation for a period of six years, during which period a considerable number of tests of various kinds were undertaken with the kiln, such tests requiring at times minor alterations in the design, so that the various losses pointed out by the Professor, particularly with reference to the loss through excess air and radiation, would be eliminated in a kiln of more modern design.

With regard to the determination of fuel consumption, my understanding of the data accumulated by Professor Harrop

is that the average of the weight of the outgoing and incoming materials respectively was used as the basis for computing the coal consumption. This method, in my opinion, is not entirely fair to the kiln, inasmuch as during part of the test period operating conditions at the works made it necessary to reduce the loading of the trucks by substituting special shapes of more or less intricate design for the standard 9 in. brick with which the test was commenced. The indications therefore are, if the weight of standard 9 in. brick had been taken as the basis of coal consumption, a more economical consumption of fuel would have been obtained.

Referring to the loss due to radiation from the kiln, which Professor Harrop points out as being 45 percent, I would say that in the modern kilns this loss is greatly diminished by placing an efficient insulating medium between the interior and exterior surfaces of the kiln.

I do not believe that the heat consumed in evaporating the mechanical moisture contained in the green material should be considered as a factor of heat loss, as this feature of the kiln supplements a tunnel drier and permits the introduction of material containing more or less moisture into the kiln and being dried therein.

I agree with Professor Harrop entirely, that a test, yielding absolutely reliable results on the average performance of the kiln, should extend over a period of at least one or two weeks.

Mr. Harrop: Professor Staley's criticism of the rather circuitous method of determining the heat losses through the heating and vaporizing of the water from the several sources is justifiable if our object had been to determine in the quickest possible way the total heat in the water vapor discharged in the stock gases. However, it must be pointed out that one of the objects in carrying out this test and the subsequent calculation was to differentiate the losses and expenditures as completely as possible and show minutely the methods of calculating.

Inasmuch as the calculation covering the water from each source was handled separately for the above reason, it would seem logical to use in that calculation, the actual or assumed mean temperature of vaporization. In other words, it was

desired to have the steps in the calculation represent what actually took place in the several cases and "short cut" methods were not desired.

Regarding Mr. Balz's contention that the fuel consumption as shown by the single test presented was high, it might be stated that the average of this test with three subsequent tests of eight hours' duration each gave a fuel consumption on the same basis of slightly less than 10 percent.

Referring to the statement of Mr. Balz that he does not believe that the heat used in evaporating the mechanical water in the ware is a loss, the author wishes to say that he believes this should be considered a loss in the light that the kiln should not properly be expected to do this work (it is work that should have been completed in the drier), but that so far as the entire operation of manufacture is concerned, it might be considered an experiment (in the kiln).

In the fourth paragraph of Mr. Lovejoy's discussion, he evidently misinterprets the statement referred to. The excess air, which enters at the charging end carries heat up the stack and this heat so carried, is a loss. However, if this excess air were eliminated, there would result no noticeable increase in the efficiency of the kiln, because the excess air entering in this way, does not carry out heat, which is vital to the operation of the kiln, but merely dilutes the combustion gases as they leave the kiln and becomes heated in so doing.

Mr. Lovejoy is correct in stating that the mechanical moisture and the hydrogen in the coal are not taken into account. These factors are included, however, in the more complete calculation which is to be published by the U. S. Bureau of Standards.

Mr. Lovejoy suggests a continuous gas sampler. Such an apparatus was designed by the author and used in this test and as the analyses of the several continuous samples were arranged together on the basis of the length of time of collecting each sample, the result was equivalent to a continuous gas sample taken throughout the entire test.

THE BURNING PROPERTIES OF SOME AMERICAN REFRACTORY CLAYS [1]

BY H. G. SCHURECHT.

During the year ending June 30, 1914, this country imported from Europe[2] 20,587 tons of common blue, and Gross-Almerode glass-pot clay valued at $180,524. This supply of clay comes chiefly from Germany, Belgium and Austria and, due to the war, it has been almost completely shut off from the United States. A knowledge of the properties of some domestic refractory clays is therefore important at the present time.

The author noticed in testing fire-clays that the load- carrying capacity of clays at furnace temperatures was increased remarkably by burning the fire-clays to higher temperatures. Bleininger and Brown[3] also noted that by burning to as high a temperature as possible the load-carrying capacity of the fire-brick is increased. Important as this relation is, practically no work has been published on American clays regarding this behavior of clays. This work was therefore done to study the burning properties of some American refractory clays with special reference to the relation between their burning temperatures and their load-carrying capacity.

Clays Studied. The following refractory clays were studied:

A — A kaolin from Gordon, Georgia.

B — A mixture composed of 90 percent Mount Savage flint clay, and 10 percent ball clay from Mayfield, Kentucky.

C — A Mount Savage plastic fire clay.

D — A ball clay from Mayfield, Kentucky.

---

[1] By permission of the Director of the U. S. Bureau of Mines.

[2] Commerce and Navigation; Bureau of Foreign and Domestic Commerce, 1914, p. 777.

[3] Bleininger, A. V., and Brown, G. H., Testing of Clay Refractories, with Special Reference to Their Load Carrying Capacity at Furnace Temperatures; *Bureau of Standards Tech. Paper 7*, 1911, p. 73.

Their analyses are as follow:

	GEORGIA KAOLIN	MOUNT SAVAGE FLINT CLAY	MOUNT SAVAGE PLASTIC FIRE CLAY	KENTUCKY BALL CLAY
Moisture loss 105°C.	0.38	1.25	0.53	1.60
Loss on ignition	13.63	12.39	10.54	11.52
SiO_2	44.25	49.60	51.90	46.87
Al_2O_3	38.06	32.65	31.91	36.58
Fe_2O_3	1.03	1.31	1.57	1.14
TiO_2	1.29	2.41	1.76	0.43
CaO	0.08	none	trace	0.50
MgO	trace	0.12	0.04	trace
Na_2O	0.10	0.33	0.29	trace
K_2O	0.70	0.38	1.61	1.60
Sulphur	0.06	0.13	0.03	0.06
Total	99.58	100.57	100.17	100.30

Description of Work. The burning and shrinkage behavior of the clays were studied by firing test pieces, 2 by 1 by 1 inches, at the rate of about 20° C. per hour, and the pieces were drawn out at intervals commencing at 1210° C. and finishing at 1410° C. which temperatures correspond approximately to cones 4 and 14 respectively. The temperatures were measured by means of platinum platinum-rhodium thermocouples and a Leeds Northrup potentiometer. The porosities and volume shrinkages were determined on each piece. The porosities were determined by weighing the pieces dry, saturated with water, and finally suspended in water. The apparent porosity was then calculated from the following equation:

$$Apparent\ Porosity = \frac{(W - D)}{(W - S)}\ 100$$

Here W equals the weight of the saturated briquette, D equals the weight of dry briquette and S equals the weight of saturated briquette suspended in water. The volume shrinkages were calculated in terms of dry volume.

The test pieces for measuring the relation of the burning temperatures of the clays to their load-carrying capacity at furnace temperatures were made 7 by 1 by 1 inches, and these

were fired at intervals between 1210° C. and 1410° C. The load which was applied transversely was three pounds for pieces having an inch cross-section. The test pieces were supported six inches apart on fire-clay knife-edges, and the load which was a fire-clay weight was applied in the middle. The kiln was then fired at a rate of about 20° C. per hour up to 1410° C. corresponding approximately with cone 14. Where the test pieces broke in firing, the breaking temperature was observed through a peep hole. This breaking temperature was the temperature at which the pieces broke and could easily be observed. In cases where deformation resulted, the same was measured on both the upper and lower side of the piece by means of an Ames dial.

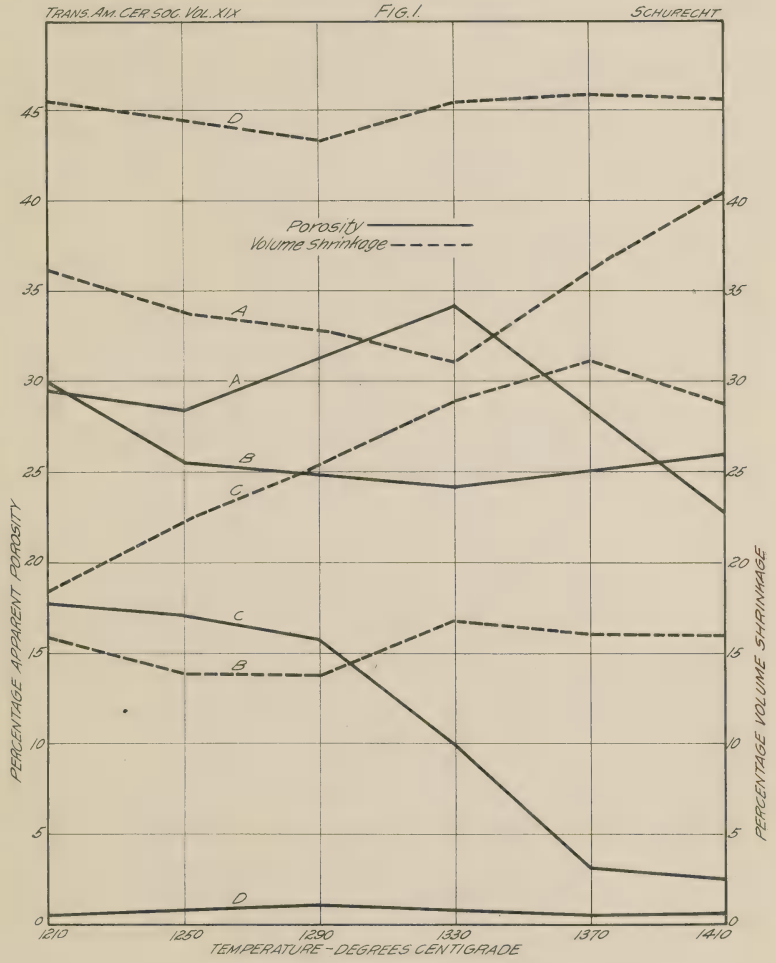
For pieces having less than an inch cross-section lighter loads were applied and the following formula was used, in which F is the load (pounds), l the span (inches), b and d the width and depth, (inches).

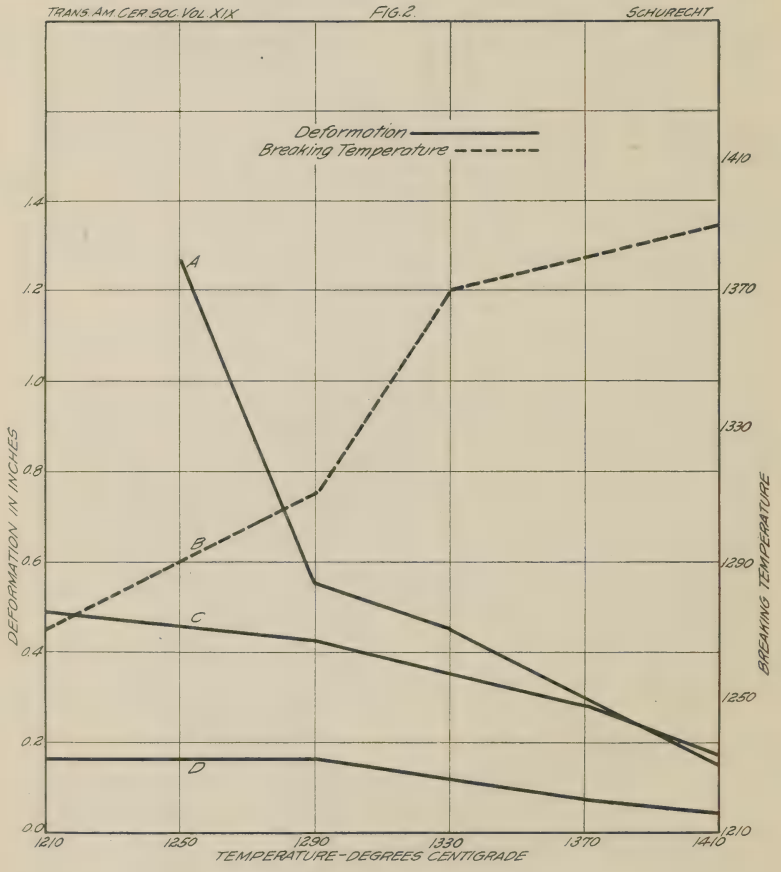
$$27 = \frac{3\,F\,l}{2\,b\,d^2} \qquad \frac{9\,F}{b\,d^2}$$

Results. The results of this work are shown in Table I and Figs. 1 and 2. By examining the porosity data it is seen that clays **A** and **B** are open burning clays and very refractory showing only slight signs of vitrifying at 1410° C. Clay **C** starts to vitrify between 1330° C. and 1370° C. while clay **D** is vitrified below 1210° C. Clays **D** and **A** have large burning shrinkages, but they do not vary much between the temperatures 1210° C. and 1410° C., while clay **C** shows a big increase in shrinkage as the burning temperature is increased.

On examinaing the load-carrying capacity data at furnace temperatures, it appears that in all cases this is improved by burning the clay to a higher temperature. The open burning clays **B** and **A** are most improved by burning to a higher temperature while the closer burning clays **D** and **C** are not improved quite as much.

Conclusions. The load-carrying capacity of refractory clays can be increased by burning refractory clays to higher temperatures. Open-burning clays like **B** and **A** are most improved, while clays which vitrify at lower temperatures like **D**


TRANS. AM. CER SOC. VOL. XIX
FIG. 1.
SCHURECHT
Porosity
Volume Shrinkage
D
A
A
B
C
C
B
D
45
40
35
30
25
20
15
10
5
0
1210
1250
1290
1330
1370
1410
TEMPERATURE - DEGREES CENTIGRADE
PERCENTAGE APPARENT POROSITY
PERCENTAGE VOLUME SHRINKAGE


TRANS. AM. CER. SOC. VOL. XIX
FIG. 2.
SCHURECHT
Deformation
Breaking Temperature
A
B
C
D
DEFORMATION IN INCHES
BREAKING TEMPERATURE
TEMPERATURE - DEGREES CENTIGRADE
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1210
1250
1290
1330
1370
1410

and C are not improved as much although a marked improvement is noticed even in these clays.

The fire-shrinkage is, in some cases, reduced by burning the clay to as high a temperature as possible. This is especially true with clay C.

Why the strength of refractory clays is improved by burning to as high a temperature as possible is still uncertain but one of the factors causing this is undoubtedly the refractoriness of the fused portion of the clay which gives the clay strength at furnace temperatures.

TABLE I — BURNING PROPERTIES OF SOME AMERICAN REFRACTORY CLAYS

TEMP. ° C.		1210	1250	1290	1330	1370	1410
Apparent Porosity, Percent	A	29.45	28.33	31.02	34.15	28.53	22.78
	B	30.00	25.53	24.75	24.20	25.05	25.85
	C	17.75	17.20	15.73	10.00	3.06	2.58
	D	0.43	0.50	0.82	0.76	0.57	0.59
Volume Shrinkage, Percent	A	36.01	33.05	32.88	31.10	36.05	40.40
	B	15.80	14.00	13.81	16.87	16.13	15.97
	C	18.65	22.20	25.20	.....	.....	.....
	D	45.50	44.10	43.40	.....	.....	.....
Deformation, Inches	A	.....	1.24	0.55	0.42	.....	0.16
	C	0.49	.....	0.43	0.35	0.28	0.16
	D	0.16	0.16	0.16	.....	0.08	0.05
Breaking Temperature, ° C	B	1270	.....	1310	1370	.....	1390

THE MAGNESITE DEPOSITS OF THE GRENVILLE DISTRICT, QUEBEC [1]

BY M. E. WILSON.

As a consequence of the present war, the source of supply of numerous mineral materials formerly imported into America from abroad has been partially or completely cut off so that since the outbreak of the war, special attention has been directed to such deposits of these minerals as were known to occur at home. Among the minerals of this class one of the most important is the magnesium carbonate, magnesite, the world's supply of which was formerly derived almost entirely from deposits in Austria-Hungary and Greece. The restricted importation of this material especially during a period of unprecedented activity in the metallurgical industries has brought about a complete transformation in the market conditions for magnesite in America.

The almost complete dependence of the American consumer of magnesite on foreign sources of supply prior to the war, and the readjustment which is now taking place is indicated by the statistics of importation and domestic production. In 1913, the year preceding the outbreak of the war, 172,591 short tons of calcined magnesite and 22,872 tons of crude magnesite were consumed in United States of which (only 9,632 tons of crude) less than 3 percent was produced at home, while in 1915 the total consumption of magnesite in United States was 26,574 short tons of calcined and 80,267 short tons of crude, of which approximately 23 percent was domestic production. Likewise the production of magnesite in Canada increased from 515 tons valued at $3,335 in 1913 to 55,413 tons having a value of $563,829 in 1916.

Up to the present time, the increase in the domestic production in North America has been derived almost entirely from Canadian deposits situated a few miles north of the Ottawa river in the Grenville district, Quebec, and from the numerous scat-

[1] Published with permission of the Director of the Geological Survey of Canada.

tered occurrences in the state of California. Although the Canadian magnesite contains considerably more lime than the California magnesite and in this respect is of inferior quality, it can be marketed in the principal manufacturing centers of eastern America for ½ to 1/3 less than California magnesite, and, on this account, large quantities of the Canadian product are now being used both in eastern United States and Canada.

Geology of the District. The Grenville district lies on the southern border of the Laurentian highlands which occupy nearly the whole of northeastern Canada, and, in common with the larger part of this great upland, is underlain by a complex of ancient Pre-Cambrian (Archaean) formations. This complex, while represented in the Grenville district by an exceedingly heterogeneous assemblage of rocks, has, nevertheless, the one common characteristic, that all of its members have been transformed to the crystalline or foliated condition as a result of the intense metamorphism to which they have been subjected.

If classified merely on the basis of age, the rocks found in the Grenville district belong to only three groups: (1) The Grenville series consisting of recrystallized marine sediments, (2) a group of igneous pyroxenic rocks intrusive into the Grenville series — the Buckingham series — and (3) batholithic masses of granite and syenite gneiss, intruding both the Grenville and Buckingham series; but the metamorphic action of the Buckingham series on the limestone members of the Grenville series has transformed extensive masses of this rock into diopside and related minerals forming a fourth common rock type generally known as 'pyroxenite'.

All of the magnesite deposits so far discovered in the district occur in association with the rocks of the Grenville series, so that it is this group of rocks that is of special interest in this connection. The series is composed of three principal members, — crystalline limestone, sillimanite-garnet gneiss and quartzite, — which, it is believed, were originally laid down as alternating beds of shale sandstone and limestone, and were later transformed to their present condition by metamorphism. The reasons for this conclusion are the following: (1) chemical analyses of the sillimanite-garnet gneiss have shown it to have the chemical

composition of a shale and thus the three rock types —sillimanite-garnet gneiss,. quartzite, and crystalline limestone — have respectively the composition of the three dominant members of normal sedimentary series, and (2) these rocks occur interstratified with one another in a manner similar in every respect to the way in which normal bedded deposits usually occur.

The rocks of the Grenville series being the least resistant to erosive agencies of all the rocks of the complex are generally found to underlie the valleys of the district, and the magnesite deposits, since they are everywhere associated with the rocks of the Grenville series are likewise always found in the valleys.

THE MAGNESITE DEPOSITS

General Character. The magnesite deposits of the Grenville district occur in extensive outcrops or groups of outcrops protruding through the marine clay and sand which in the Grenville district, as elsewhere in the Laurentian highlands adjoining the lower Ottawa and the lower St. Lawrence, form flats in the bottoms of the major valleys. They are mainly composed of magnesite, dolomite and serpentine, but also include small quantities of diopside, talc, phlogopite, quartz and other minerals.

The magnesite contained in the deposits is a glistening, cream-white to milk-while, or gray material occurring in extensive masses associated with bands or lenses of dark green to light yellow serpentine. Serpentine also occurs disseminated in the magnesite, in places, and the magnesite, nearly everywhere contains more or less included dolomite; and, since dolomite ($CaMg(CO_3)_2$) contains 30 percent of lime the magnesite generally contains a certain amount of this constituent, the percentage present varying in proportion to the amount of dolomite which the magnesite contains. In a few localities the dolomite included in the magnesite is more coarsely crystallized and is whiter in color than the surrounding material, and can be distinguished in this way; but throughout the great mass of the deposits the magnesite and dolomite are so similar in appearance that the presence of the dolomite is difficult to detect.

The intimate manner in which the dolomite is disseminated through the magnesite is made evident in several ways. Where

the magnesite outcrop has been exposed to atmospheric agencies, the dolomite being more soluble than the magnesite dissolves away more readily, so that the weathered surface presents an irregular pitted appearance, the magnesite forming the prominences and the dolomite occupying the bottoms of the depressions. The presence of the dolomite in the magnesite can also be detected by treating the mixture with cold, strong hydrochloric acid, effervescence taking place where the dolomite is present.

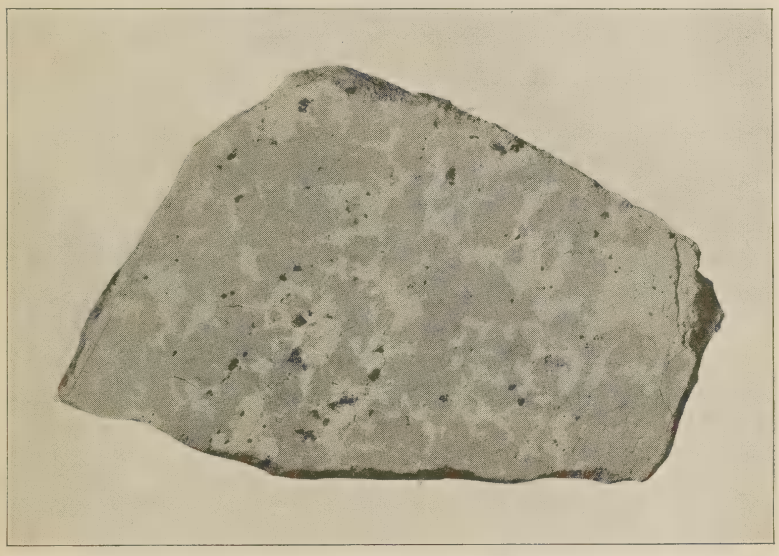


FIG. 1.

The relationship of the dolomite to the magnesite can best be observed, however, in the material after it has been calcined in a kiln or furnace without access of air (deoxidizing atmosphere), the dolomite assuming a white and the magnesite a pink color as a result of this operation. A number of specimens of magnesite collected by the writer were sawn and calcined in the ceramic laboratory of the Mines Branch of the Canadian Department of Mines, by Mr. H. Frechette, with the result shown in Figures 1 and 2. It will be observed that in these specimens the dolomitic

portions appear to be included in the magnesite and possess a most irregular outline.

Structure. The principal structural features observed in the magnesite deposits were parallel planes of parting resembling planes of bedding, parallel banding, masses having a lenticular form faults, slickensided faces, crumplings and other evidences of deformation. The banded structure exhibited by the deposits arises in part from variations in the color of the magnesite and in part from variations in the proportion of disseminated serpentine which it contains. The lenticular form com-

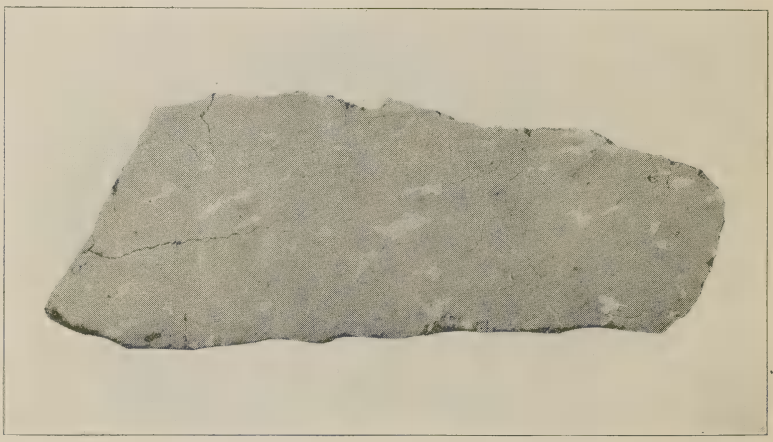


FIG. 2.

monly observed in the deposits is probably the result of deformation, certain portions of the deposits of slightly different composition or physical character being more resistant to deformation than other portions of the deposits.

Origin. From the study of the character and relationships of the magnesite deposits it has been concluded that they have been formed by the replacement of the crystalline limestone member of the Grenville series through the agency of solutions emanating from the pyroxenic igneous intrusives composing the Buckingham series. They have thus probably originated in a

manner very similar to that suggested by Redlich[2] for the Austro-Hungarian deposits.

Quality of Magnesite. The proportion of magnesite free from dolomite, or dolomite free from magnesite in the magnesite deposits, is excedingly small, the larger part consisting of an intimate mixture of magnesite and dolomite in varying proportions. There are considerable masses of material present, however, in which the lime content resulting from the presence of the dolomite ranges from 3 to 12 percent. It is the practice at the mines at present to mine only these portions of the deposits, so that a product averaging from 6 to 10 percent lime is obtained.

Extent of Deposits. Up to the present time deposits of magnesite have been found in four principal localities in the Grenville district. At all of these points there is present extensive deposits of marketable magnesite in which the proportion of serpentine and highly dolomitic magnesite, to be removed by cobbing or in mining the material, is less than 40 percent. From an examination of the surface outcrops of the deposits and from the results of diamond drilling operations, it has been estimated by the writer that approximately three-quarters of a million tons of magnesite, averaging from 7 to 10 percent lime, is known to be present in the district.

[2] Redlich, Karl A., Die Bildung des Magnesits und sein naturliches Vorkommen, *Fortschritte, der Min., Krist., and Petr., Vol. IV,* pp. 9-43, 1914.

A NEW PRINCIPLE IN TEMPERATURE MEASUREMENT

BY W. C. HARTER, TRENTON, N. J.

Because you are engaged in scientific pursuits, you will doubtless be interested in a late development of one of our American scientists, Dr. E. F. Northrup, of the faculty of Princeton University. Dr. Northrup's new "Pyrovolter principle" has made possible a distinct advance in the laboratory and commercial measurement of high temperatures, and marks a definite improvement in the field of thermocouple pyrometry.

For the indication of temperatures by means of thermocouples, experience has proved that the deflection instrument is by far the most suitable for commercial use, because of the ease with which it can be read, and because of its general simplicity. For this reason an instrument of this type has been adopted as standard for the large majority of so-called "pyrometers." However, the ordinary deflection instrument, used in series with the thermocouple circuits, has certain inherent faults which tend to neutralize its advantages.

The deflection instruments used may be divided into two classifications; those of low resistance and those of high resistance. The low resistance instruments are suitable for use only with base metal couples, and have a very marked tendency to inaccuracy because of outside lead resistance. The high resistance instruments — which are the general type for use with platinum-rhodium couples, attempt to render negligible the outside lead resistance by introducing a high and unnecessary resistance into the instrument itself. The effect is merely to approach toward accuracy.

It must be noted that, although a high resistance pyrometer indicator or recorder may be calibrated correctly when it is made, it is bound to lose its accuracy as the thermocouples age and acquire a higher resistance, very appreciably increas-

ing the resistance of the outside circuits and consequently making the temperature indications below their true value.

Also, in all ordinary deflection instruments, the readings change to at least some extent with change of temperature at the instruments itself, due to the fact that copper wire, which must be used for certain parts, has a considerable temperature resistance coefficient.

For these reasons, it has long been evident that ordinary deflection instruments cannot consistently and permanently measure temperatures with the degree of accuracy demanded by scientists and commercial workers desirous of correct results. Hence, the potentiometer has been employed to a considerable extent for the accurate measurement of thermocouple temperatures.

The potentiometer, by its very nature, inasmuch as it reads electro-motive force and not current, is independent of the outside lead resistance, and is therefore not subject to the deflection type's inaccuracy from this source. However, the potentiometer is a comparatively delicate instrument, its manipulation is complicated, and the cost is high. It does not permit the facility of reading which is the main advantage of the deflection type.

There has, therefore, been felt a definite need for an instrument combining the simplicity of the deflection type with the accuracy of the potentiometer. It has been to fill this need that Dr. Northrup's Pyrovolter has been developed.

The Pyrovolter is in reality a principle, not an instrument. This principle has made possible the construction of an instrument which indicates temperature direct, on a scale, as does the ordinary deflection pyrometer indicator, and does this by reading electro-motive force, and not current — in this respect corresponding to the potentiometer. To those unacquainted with electrical terms, who may not see the advantage of this distinction — this is equivalent to measuring the steam pressure of a boiler. The current measuring instruments do what is analogous to measuring the quantity of steam passing out of that boiler thru a pipe of known bore, and judging the pressure by

the flow of steam. The Pyrovolter, however, draws no current from the source of the E. M. F. being measured.

For this reason, the same as in the potentiometer, the Pyrovolter readings are independent of the resistance of the circuit in which the E. M. F. is located; *i. e.,* independent of the outside lead resistance. In less technical terms, this means that the lead wires coming from thermocouples to an instrument may be of any length, ten feet, a thousand feet, or even more, and the accuracy of the readings will in no wise be affected. Heretofore, when it has been desired to read several couples, from different distances, on one indicator, thru a selector switch, external resistance was arbitrarily introduced to make all leads of the same resistance, or else, as indeed has more often been the practice in commercial installations, the differences in these outside resistances have been practically disregarded, makers considering that the high resistance of the instruments would sufficiently offset any errors, so that accuracy would not be greatly affected until the couples had aged, when the whole system must be re-calibrated. With the Pyrovolter, it is immaterial whether the couple is newly constructed and of low resistance, or old and corroded; whether you heat just one end of the couple and increase the resistance a small amount, or whether you heat a long portion, thus changing the resistance of the couple very considerably, whether you use a heavy No. 6 B. and S. wire couple of extremely low resistance, or a .1 millimeter platinum platinum-rhodium couple of possibly 100 ohms resistance with an E. M. F. of only a few millivolts.

The Pyrovolter has no temperature coefficient of resistance, and hence its readings do not change with change of temperature at the instrument. This has been made possible by the use of Manganin wire in that part of the Pyrovolter circuit which determines the range of the instrument, and has been done without the sacrifice of either durability or robustness. The temperature resistance coefficient has not been merely reduced or minimized, it has been **eliminated,** — something never before accomplished in a deflection instrument.

The Pyrovolter principle has made possible the construction of an instrument permitting a very wide flexibility of range without complication. One instrument can be adapted to read from both base-metal and noble metal couples, using the full scale for each couple. Theoretically, there is no limit to the number of ranges which may be applied to the same instrument without affecting the simplicity of operation of the instrument. It is true that all other deflection instruments can have a multiplicity of ranges applied to them, but with such, as the series resistance is reduced, the temperature coefficient increases. In the Pyrovolter the coefficient is not affected.

This new principle has made possible not only the construction of an instrument which measures temperatures accurately, but has also made possible the construction of such an instrument in a very rugged and durable type. The deflection meter used is of the strong spring control, double pivot type of low resistance millivoltmeter. To accomplish results approaching in accuracy those of the Pyrovolter, it is unnecessary to use a suspended coil type of high resistance meter, as is ordinarily employed for use with platinum couples and for base metal couples where even a fair degree of accuracy is desired. The Pyrovolter can read with facility from platinum couples, since its uses a sturdy jewel bearing meter of standard make, constructed for hard shop service. It has accomplished a definite step forward in getting away from the suspended coil, high resistance instruments, which are essentially delicate, having a large dead resistance in series, which necessitates a very sensitive moving element and a correspondingly weak control. The purpose of this resistance is only to make the external resistance (*i. e.*, the lead resistance) small in percentage effect. If we should introduce a platinum-rhodium couple of high resistance into the circuit, and this in time should cause a resistance variation of 50 ohms, an instrument of 400 ohms would show an error of 12½ percent, and an instrument of as high as 1200 ohms — which is about the limit — would show the very appreciable error of 4 percent. It is obvious that it is advisable to eliminate this dead resistance and use a low resistance meter if possible.

To show how this is possible, and to explain the Pyrovolter principle itself, it will be necessary to refer to a couple of diagrams.

Referring to Figure 1, a small dry cell *Ba*, contained in the case of the instrument, sends a current thru the rheostat *R* and the fixed resistance *Cu* (which are equal in value to the resistance of the copper coil of the moving element of the meter *G*), and *S*, a fixed resistance of Manganin adjusted accurately with potential tap-offs. The value of the resistance included between these potential leads determines the range of the instrument. The current flowing thru *S* is varied by the rheostat *R*, so that a varying E. M. F. is applied to these potential leads due to the drop of potential over the resistance *S*. The moving element is connected in series with the unknown E. M. F., *Ex* (thru the binding posts *P1* and *P2*), across this varying potential, so that the meter serves as a galvanometer to establish a balance between the unknown *Ex* and the drop across *S*. This adjustment is effected by turning a large black button in the lower right hand corner of the instrument in a clock-wise direction to increase the current flow thru *S*, thus increasing the drop across *S*. When the balance has been obtained — and this takes only a second — a small button on the instrument is pressed, which changes the connections to those of Figure 2.

In the new connections (Figure 2), it will be noted that the pressing of the button has substituted the meter *G* for the resistance *Cu*. This substitution is permissible for all temperatures at the instrument, since both elements are copper and hence always of the same resistance; so that now without affecting the conditions of the circuits, there has been introduced a meter which measures the current flowing thru *S*, and, since the drop across *S* is proportional to the current flowing thru *S*, the scale of the meter is marked off to read the drop across *S*, and this drop having just been balanced against *Ex*. — the unknown E. M. F., — we have the instrument indicating the value of *Ex*.

In effect the Pyrovolter principle provides a means of operating a deflection instrument on the potentiometer principle,

TRANS. AM. CER. SOC. VOL. XIX HARTER

FIG. 1

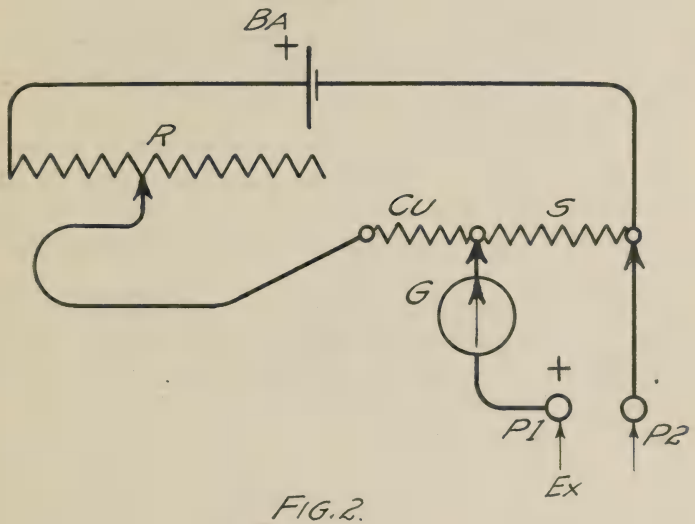
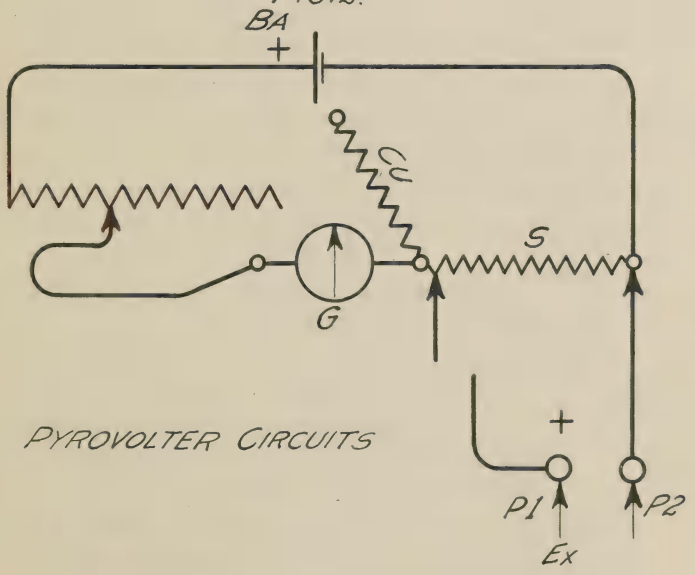


FIG. 2.



PYROVOLTER CIRCUITS

wherein the accuracy and permanence of the instrument basically depend upon a permanent magnet rather than upon a standard cell, in that the "current constant" of the instrument is all that affects the readings, the resistance S being once fixed. As the reliability and permanence of a permanent magnet is quite equal to that of a standard cell, the practicability of this principle is at once evident.

In the Pyrovolter principle, nothing is employed that is new or novel except the circuits by means of which the parts are connected. No dependence is laid on a delicate, sensitive galvanometer, carefully calibrated slide wire, or fragile standard cell.

As the Pyrovolter is a principle, not an instrument, it is possible to adapt any deflection instrument to this principle, and any kind of an electrical meter operating on the d'Arsonval principle. Regardless of the former use or application of the meter, an adapter can be built which will operate it as a Pyrovolter of any range whatsoever, without affecting, in the slightest degree, its usefulness in its original capacity. It is therefore possible to convert previous pyrometric installations into a system employing the Pyrovolter principle.

In conclusion, this new principle has made possible the construction of a deflection potentiometer of rugged type, suitable for the following uses, among others:

(1) The calibration of thermocouple systems already installed, or of any type of direct current instrument in general.

(2) Wide adaptability to thermocouple pyrometry, for both base and noble metal couples.

   (a) Used in a special form with couples for the measurement of slight changes of body temperature in medical and biological research, and for the measurement of slight temperature changes in chemical reactions.

   (b) Used to measure the voltage drop of small generators, and in any similar cases where small drops of potential are present.

(c) Used to measure temperatures wherever thermocouples are employed in scientific and commercial pursuits, indicating with absolute accuracy those temperatures found in foundries, glass plants, potteries, etc.

THE EFFECT OF THE SIZE OF GROG IN FIRE CLAY BODIES[1]

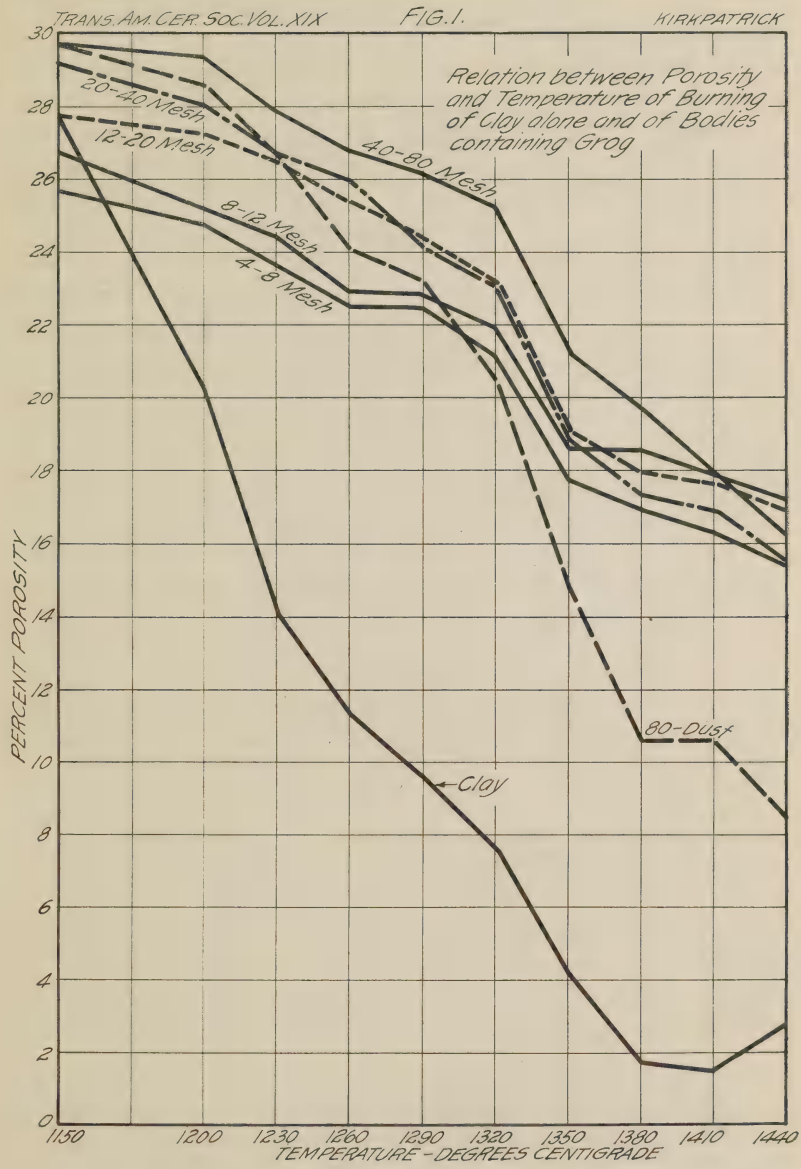
BY F. A. KIRKPATRICK.

One of the most important factors governing the properties of fire clay refractories is the size of the grog used in such bodies. Some products require coarse grog, others fine grog or mixtures. Where resistance to repeated heating and cooling is desired, the larger sizes are considered best. For resistance to deformation under load the densest body is most desirable and is obtained by use of non-plastic material composed of coarse, medium and fine particles in the proper proportions. Grog varies greatly in the percentages of different sizes depending upon the nature of the material and the method of grinding. A mechanical analysis often aids in discovering the cause of defects in a body. The present investigation was undertaken for the purpose of determining quantitatively the changes produced in some properties of fire clay bodies by variation of the size of grog.

This work was begun by Mr. G. H. Brown and Mr. H. G. Schurecht in 1915 and completed by the writer in 1916-17 along the same lines as originally planned. The investigation was begun as a study of sagger bodies, but a more general application of the results can be made.

The effect of the size of grog was studied quantitatively by Fulton and Montgomery[2] using bodies made up of 50 percent. Saint Louis fire clay and 50 percent. grog. They prepared five sizes of grog: 6, 14, 35, 100 and 200 mesh, using all material passing through the sieves. They found that the modulus of rupture in the raw state was a maximum with 100 mesh grog. In the burned state up to cone 15, strength increased with decrease of grog size. At this temperature, porosities of 6, 14 and 35 mesh bodies were 10 to 13 percent, while those of 100 and 200 mesh bodies were 5 to 6 percent.

[1] By permission of the Director of the U. S. Bureau of Standards.
[2] The Effect of Grog in Fire Clay Bodies, *Trans. Amer. Cer. Soc. XVII,* p. 409.


TRANS. AM. CER. SOC. VOL. XIX
FIG. 1.
KIRKPATRICK
Relation between Porosity and Temperature of Burning of Clay alone and of Bodies containing Grog
20-40 Mesh
12-20 Mesh
40-80 Mesh
8-12 Mesh
4-8 Mesh
80-Dust
Clay
PERCENT POROSITY
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
1150
1200
1230
1260
1290
1320
1350
1380
1410
1440
TEMPERATURE - DEGREES CENTIGRADE

A number of investigators have studied the effect of the size of materials upon the strength and other properties of cement mortar and of concrete.[3] Although the conditions are somewhat different, the present work shows that some of the deductions of these studies apply to fire-clay bodies in the raw state. They do not hold, however, for bodies in the burned state.

Methods. The general plan of procedure consisted of the separation of grog into different sizes and recombining these in arbitrary proportions. There are two principal methods of recombining the separate sizes: (1) By means of analysis curves[4]; (2) by means of triaxial diagrams.[5] The second method was adopted since it was obvious that the first would be of value only for bodies in the raw state. Strength in the burned state increases with the surface factor up to the temperature where overburning begins, and the analysis curve for maximum strength would be a straight line perpendicular to the size axis at the smallest size obtainable.

The grog was made by crushing in a wet pan high-grade fire brick which were composed of about 50 percent flint fire-clay. The grog was screened through sieves with a power shaker and separated into the following sizes: 4-8 mesh, 8-12, 12-20, 20-40, 40-80, 80-dust. Each sized portion was thoroughly mixed by means of shoveling. Mechanical analyses were made of each portion with Tyler standard screens. The sizes of the screens used were as follows:

Mesh	*Size of Opening (Inches)*	*Mesh*	*Sizeof Opening (Inches)*
4	.200	30	.0198
6	.131	40	.0150
8	.093	60	.0087
10	.072	80	.0069
12	.054	150	.0041
14	.046	200	.0029
20	.033	300	.0017

[3a] R. Feret. "Sur la Compacité des Mortiers Hydrauliques." *Annales des Ponts et Chausses, 1892, II* and other volumes.

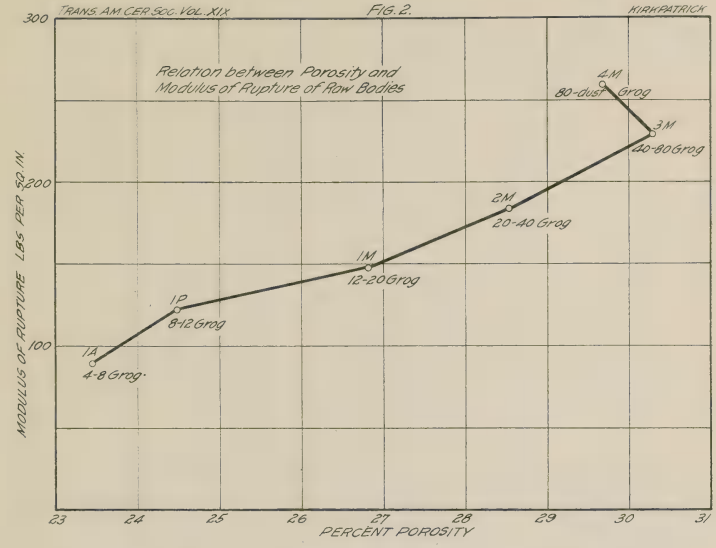
[3b] Fuller and Thompson, "The Laws of Proportioning Concrete." *Trans. Am. Soc. of Civil Engineers, Vol. LIX*, p. 67, 1907.

[3c] Taylor and Thompson, "*Concrete, Plain and Reinforced,*" pp. 132 to 216.

[3b] Wig, Williams and Gates, "Strength and Other Properties of Concrete as Affected by Materials and Methods of Preparation", *U. S. Bureau of Standards Technologic Paper No. 58.*

[4] See Taylor and Thompson, *Ref. 3c.*

[5] *See Ref. 3a.*


TRANS. AM. CER. SOC. VOL. XIX.
FIG. 2.
KIRKPATRICK
Relation between Porosity and Modulus of Rupture of Raw Bodies
4M
80-dust Grog
3M
40-80 Grog
2M
20-40 Grog
1M
12-20 Grog
1P
8-12 Grog
1A
4-8 Grog
MODULUS OF RUPTURE LBS PER SQ. IN.
PERCENT POROSITY
300
200
100
23
24
25
26
27
28
29
30
31

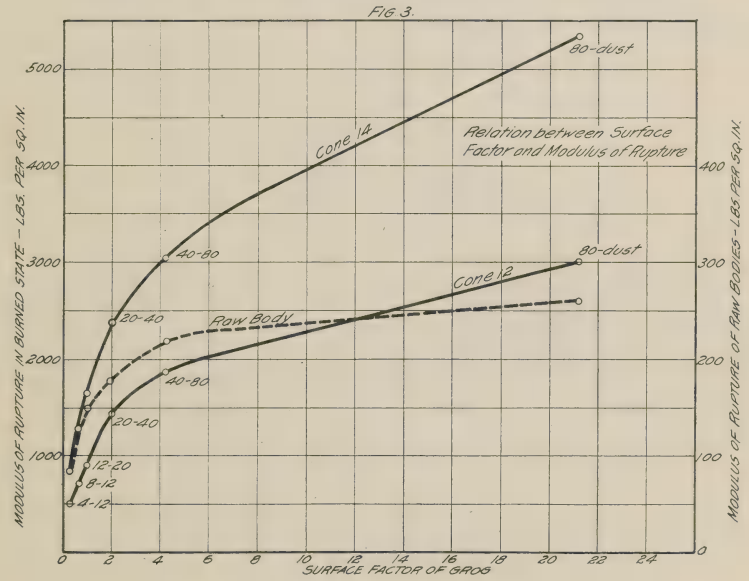


FIG. 3.
Relation between Surface Factor and Modulus of Rupture
80-dust
Cone 14
40-80
20-40
Raw Body
12-20
8-12
4-12
80-dust
Cone 12
40-80
20-40
MODULUS OF RUPTURE IN BURNED STATE - LBS. PER SQ. IN.
MODULUS OF RUPTURE OF RAW BODIES - LBS PER SQ. IN.
SURFACE FACTOR OF GROG
5000
4000
3000
2000
1000
400
300
200
100
0
0
2
4
6
8
10
12
14
16
18
20
22
24

The analyses of the separate portions were as follows:

Mesh of Screen	*Mesh of Screen*	*Percent*
4- 8	4- 6	49.4
	6- 8	50.6
8-12	8- 10	36.9
	10- 12	63.1
12-20	12- 14	26.6
	14- 20	73.4
20-40	20- 30	44.8
	30- 40	55.2
40-80	40- 60	52.7
	60- 80	47.3
80-dust	80-150	37.4
	150-200	15.8
	200-300	19.0
	Through 300	27.8

All bodies were of the composition 50 percent grog and 50 percent clay by weight. The latter was a high grade plastic fire clay ground to pass a 20 mesh screen.

The bodies were made up in five triaxial series having the following grog components:

Series	*Mesh*
1.	4- 8, 8-12, 12-20
2.	8-12, 12-20, 20-40
3.	12-20, 20-40, 40-80
4.	20-40, 40-80, 80-dust
5.	4-20, 20-80, 80-dust

In series 5, the 4-20 grog was composed of equal parts of 4-8, 8-12, and 12-20 sizes. The 20-80 grog was formed of equal parts of 20-40 and 40-80 sizes. Each series contained 16 bodies designated by letters and having the following grog composition:

TABLE I

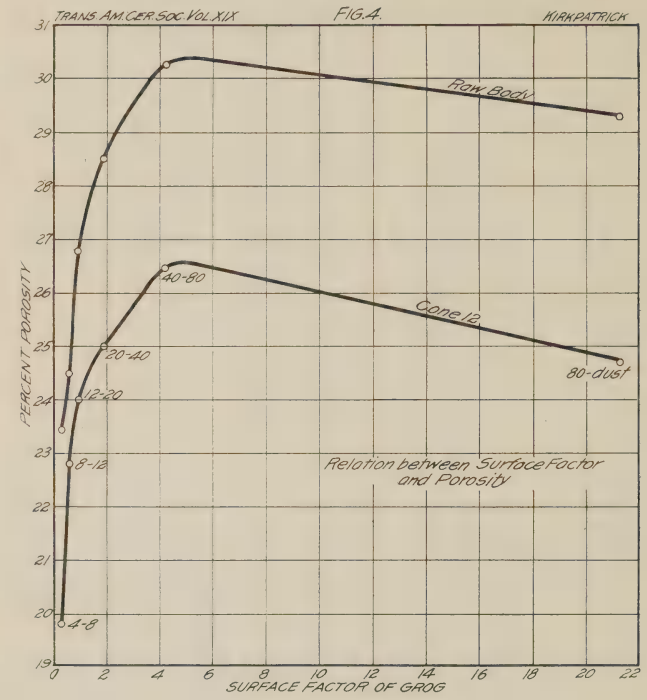
LETTER	PERCENT A	PERCENT P	PERCENT M
A	100	0	0
B	66⅔	0	33⅓
C	66⅔	33⅓	0
D	60	20	20
E	40	20	40
F	40	40	20
G	33⅓	..	66⅔
H	33⅓	33⅓	33⅓
I	33⅓	66⅔	..
J	20	20	60
K	20	40	40
L	20	60	20
M	..	..	100
N	..	33⅓	66⅔
O	..	66⅔	33⅓
P	100	..	..

The clay and grog were thoroughly mixed dry by shoveling and pugged in a wet pan. The plastic mass was allowed to stand at least two hours to allow the grog to absorb moisture. Briquettes 1 in. by 1 in. by 7 in. were molded by hand.

For the determinations of modulus of rupture in the raw state, briquettes were air dried at least three days, dried at 65° C. for one day, and finally at 110° C. for two days. These were broken in the transverse test machine described by Bleininger and Howat[6] using a 5½ inch span. The method of calculation was the same as that given by these writers. The broken 3½ inch pieces were burned and used for strength tests. Porosity of the raw briquettes was determined by immersion in kerosene in the usual manner, the average of four pieces being taken.

Bodies were burned at cones 10, 12 and 14, the rate of rise of temperature being 25° C. per hour with a two hour soaking period at the end of the burn. Modulus of rupture determinations of the burned pieces were made in a 10,000 lb. Olsen machine with a two inch span. This length of span was too small, and the values obtained for modulus of rupture are high,

[6] The Compression, Tensile and Transverse Strength of Some Clays in the Dry State, *Trans. Am. Cer. Soc. XVI*, p. 273.


TRANS. AM. CER. SOC. VOL. XIX
FIG. 4.
KIRKPATRICK
PERCENT POROSITY
SURFACE FACTOR OF GROG
Raw Body
Cone 12
40-80
20-40
12-20
8-12
4-8
80-dust
Relation between Surface Factor and Porosity

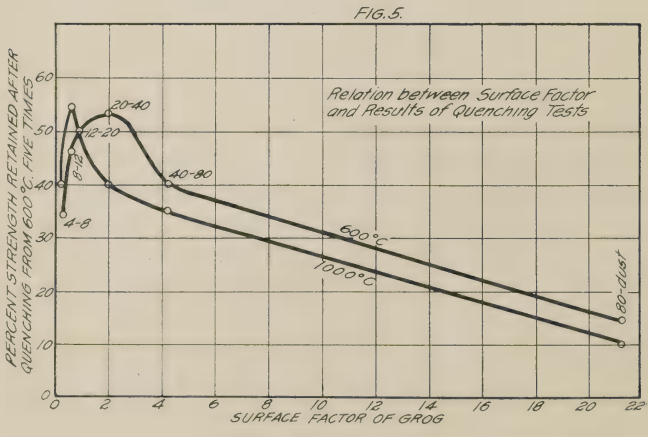


FIG. 5.
PERCENT STRENGTH RETAINED AFTER QUENCHING FROM 600°C. FIVE TIMES
SURFACE FACTOR OF GROG
Relation between Surface Factor and Results of Quenching Tests
20-40
12-20
8-12
4-8
40-80
600°C
1000°C
80-dust

because they include a certain proportion of the shearing strength. Porosity determinations were made in the usual manner.

In order to determine the behavior of the burned bodies under repeated heating, two sets of experiments were made. In the first set, briquettes previously burned to cone 12 were heated five times to 600° C. and quenched in ice water after each heating. The modulus of rupture was then determined, using a two inch span, the average of six pieces being taken. The strength after treatment expressed as a percentage of that before treatment afforded a means of comparison of the value of the bodies in repeated heating.

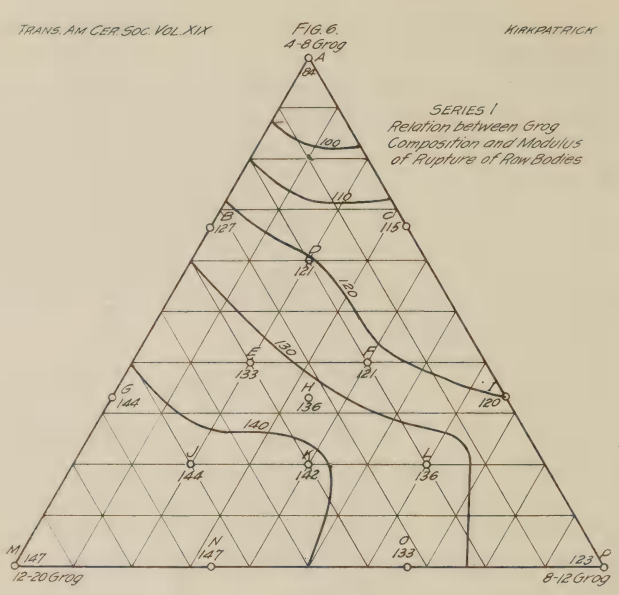
In the second set of experiments, bars 1 in. by 1 in. by 7 in. previously burned to cone 12, were heated to 1,000° C. and quenched in running water at about 15° C. a sufficient number of times to cause them to break in two. Four briquettes of each body were used. The number of quenchings withstood before breaking afforded a means of judging the relative value of the bodies under severe conditions of heating and cooling.

A draw trial burn was made with bodies containing the six separated sizes of grog: 4-8 mesh, 8-12, 12-20, 20-40, 40-80, 80-dust, and a body containing 100 percent. clay. Porosities were determined at intervals of 30° C. for temperatures from 1150° C. to 1440° C.

RESULTS FROM SINGLE SEPARATED SIZES

In Fig. 1 is shown the relation between temperature of burning and porosity for bodies containing the separated sizes and for the clay alone. It is noted that the 80-dust body has a greater rate of vitrification than any of the other grog bodies, due to the finer grog offering more surface for solution by the clay. The curves for the larger sizes are close together, and the rates of vitrification are less than that of the 80-dust body. That is, the 80mesh grog forms a dividing line between coarse or slowly vitrifying and fine or rapidly vitrifying grog sizes. Hence, at commercial temperatures of burning, some fine grog is necessary for development of high strength by vitrification.

In Fig. 2 is given the strength-porosity curve for raw bodies. From 4-8 mesh to 40-80 mesh grog, strength increased


TRANS. AM CER SOC. VOL. XIX
FIG. 6.
4-8 Grog
KIRKPATRICK
SERIES I
Relation between Grog Composition and Modulus of Rupture of Raw Bodies
A 84
B 127
C 115
D 121
E 133
F 121
G 144
H 136
I 120
J 144
K 142
L 136
M 147
N 147
O 133
P 123
100
110
120
130
140
12-20 Grog
8-12 Grog

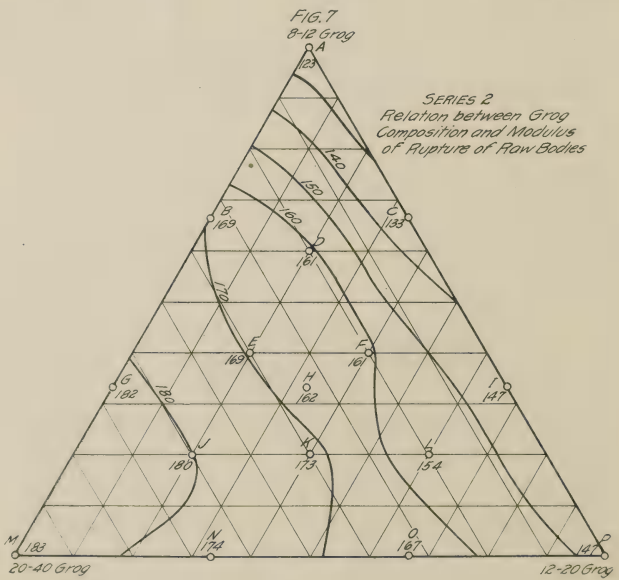


FIG. 7
8-12 Grog
SERIES 2
Relation between Grog Composition and Modulus of Rupture of Raw Bodies
A 123
B 169
C 135
D 161
E 169
F 161
G 182
H 162
I 147
J 180
K 173
L 154
M 183
N 174
O 167
P 147
140
150
160
170
180
20-40 Grog
12-20 Grog

with increase of porosity, this being due probably to cracks developed in drying. The size of the cracks decreased with decrease in size of grog. From 40-80 mesh to 80-dust strength decreased in the usual order with increase of porosity.

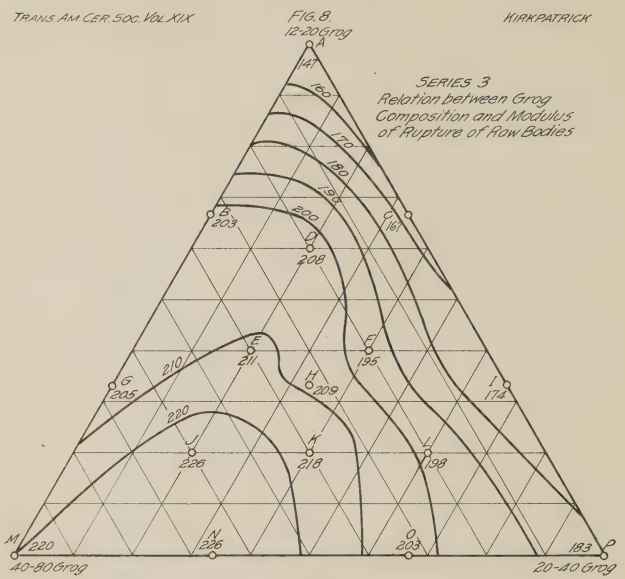
In Fig. 3 is shown the relation between surface factor and modulus of rupture in the raw and burned states. The surface factor was calculated according to the method suggested by Purdy[7] and includes the grog portion only. Strength increased with increase of surface factor. Porosity in the raw and burnt states was a maximum in the 40-80 mesh body (Fig. 4). The results from the quenching tests are given in Fig. 5. Bodies containing the larger sizes of grog withstood the tests best.

RESULTS FROM MIXTURE OF SIZES

Drying Properties. Figures 6 to 10 show the relation between grog composition and modulus of rupture for raw bodies. The curved lines within the diagrams are iso-strength lines. Strength increased with increase of surface factor in series 1 and 2 but not in series 3 and 4 (Fig. 11). Strength increased with increase of porosity in series 1, 2, and 3 and with decrease of porosity in series 4 (Figs. 2, 12, and 13). The following considerations are offered in explanation of these results. It is obvious that mixtures of sizes give denser bodies than single sizes if they are related to each other so that the smaller sizes fit into the voids between the larger sizes. Since clay and grog have approximately the same specific gravity they occupy about the same volume per unit volume of briquette body. Hence, the grog particles are in contact with each other in the raw body except for a comparatively thin layer of clay.

In the Table II are given the average size of each grog portion and the ratio between the three average sizes in each series:

[7] The Calculation of the Comparative Fineness of Ground Materials by Means of a Surface Factor. *Trans. Amer. Cer. Soc. VII*, p. 441.


TRANS. AM. CER. SOC. VOL. XIX
FIG. 8.
12-20 Grog
KIRKPATRICK
SERIES 3
Relation between Grog Composition and Modulus of Rupture of Raw Bodies
A
141
160
170
180
190
200
B
203
C
161
D
208
E
211
F
195
G
205
H
209
I
174
J
226
K
218
L
198
M
220
N
226
O
203
P
183
40-80 Grog
20-40 Grog

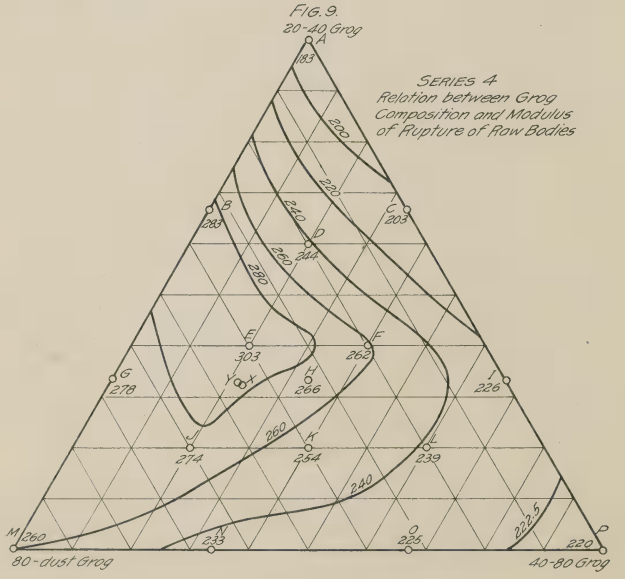


FIG. 9.
20-40 Grog
SERIES 4.
Relation between Grog Composition and Modulus of Rupture of Raw Bodies
A
183
200
220
240
260
280
B
203
C
203
D
244
E
303
F
262
G
278
H
266
I
226
J
274
K
254
L
239
M
260
N
233
O
225
P
220
80-dust Grog
40-80 Grog

TABLE II

SERIES	MESH	AVERAGE SIZE INCHES	RATIO OF SIZES
1	4- 8	.1382	1.00
	8-12	.0697	.50
	12-20	.0423	.30
2	8-12	.0697	1.00
	12-20	.0423	.61
	20-40	.0214	.31
3	12-20	.0423	1.00
	20-40	.0214	.51
	40-80	.0101	.24
4	20-40	.0214	1.00
	40-80	.0101	.47
	80-dust	.0032	.15
5	4-20	.0834	1.000
	20-80	.0157	.188
	80-dust	.0032	.038

If spheres of equal volume are packed symmetrically in a receptacle two sizes of voids are formed between them, one half having a diameter 0.41 times that of the large spheres, the other half 0.22 times.[8] Hence, the three sizes of spheres necessary to form the densest mass have diameters in the ratio 1.00 ; 0.41 : 0.22. Since the actual shape and size of voids in clay-grog bodies cannot be determined, the best means at hand for comparison of the effect of mixing different sized particles must be used. As the above table shows, the ratio of sizes in series 1 and 2 is such that the smaller particles do not fit into the voids, but separate the larger particles. Hence, there are no maximum strength nor density areas in these series. In series 3, there is a somewhat better ratio. The 40-80 size fits into the voids between either 12-20 or 20-40 mesh size, giving considerable increase in strength with amounts of 30 percent and more, and a maximum strength area near bodies J and N.

In series 4 the ratio approaches the theoretical ratio for spheres. The voids in the 20-40 material are able to contain 80-dust material, but most of the 40-80 grog is too large, separating the larger particles causing increase in porosity and decrease in strength.

[8] See *Ref. 3c*, p. 168.

FIG. 10

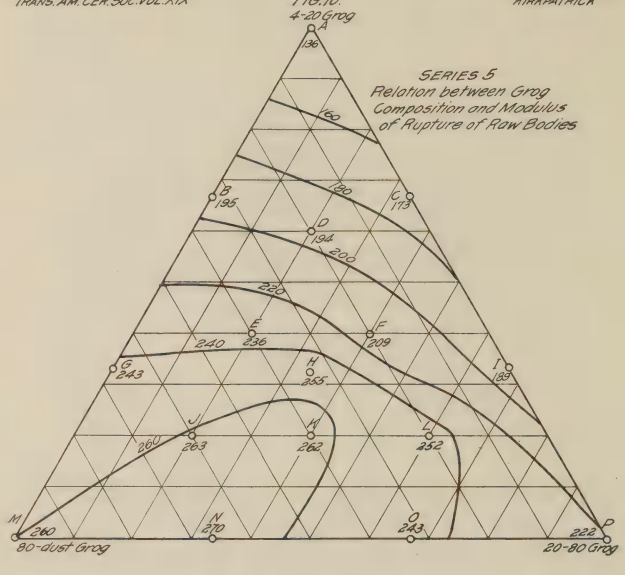
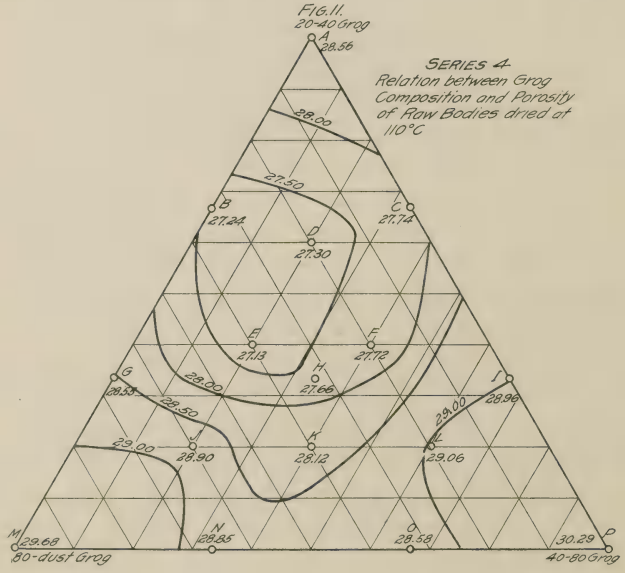

4-20 Grog
A
136
SERIES 5
Relation between Grog Composition and Modulus of Rupture of Raw Bodies
160
B
195
180
C
113
D
194
200
220
E
240
236
F
209
G
243
H
255
I
189
J
260
263
K
262
L
252
M
260
N
270
O
243
P
222
80-dust Grog
20-80 Grog

FIG. 11.

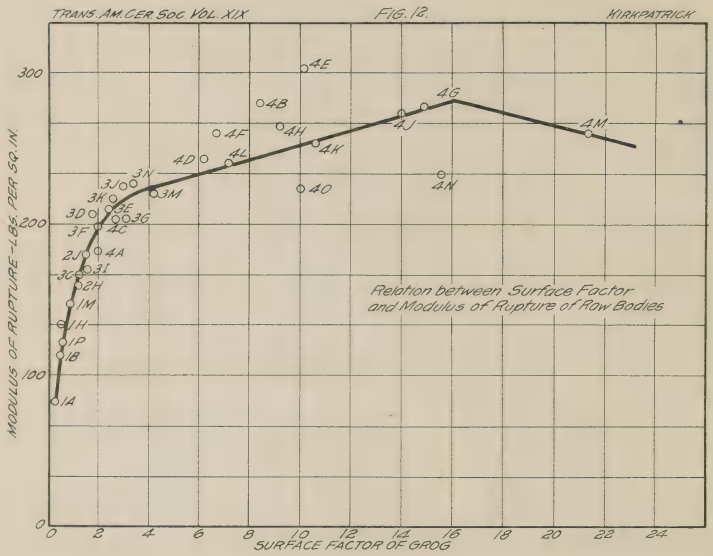

20-40 Grog
A
28.56
SERIES 4
Relation between Grog Composition and Porosity of Raw Bodies dried at 110°C
28.00
27.50
B
27.24
C
27.74
D
27.30
E
27.13
F
27.72
G
28.33
28.00
H
27.66
I
28.96
28.50
29.00
J
28.90
K
28.12
L
29.06
29.00
M
29.68
N
28.85
O
28.58
P
30.29
80-dust Grog
40-80 Grog

In series 5 the ratio of sizes shows that the smaller sizes easily fit into the voids between the 4-20 size, giving some of the densest bodies obtained. These were not, however, the strongest. Most of the bodies in series 4 were stronger than those in series 5. The latter were weakened by the isolated large particles and by the cracks formed by these particles in drying, as in series 1 and 2, which contained large grog.

While the ratio of sizes affords a convenient means of comparison it should be noted that the average size of each grog portion was used, but that each portion contained particles varying in size from the maximum to the minimum. A more accurate method of study is offered by the analysis curves of the grog portions. The curve of the strongest mixture is different for each group of similar mixtures. It may be a parabola, ellipse and straight line, straight line alone, or of some other form. Whatever be the form, the curve shows accurately what the ratio of sizes shows approximately; that the mixture is so proportioned that the smaller sizes fill the voids most completely. Analysis curves are not given for series 1, 2, and 3 since those for series 4 and 5 (Figs. 14 and 15) will serve to explain their use.

Ordinates represent the percentage passing screens having openings of the sizes indicated along the abscissæ. The curves denoted as "Parabola" are Fuller's curves of greatest strength. In series 4, Fig. 14, the curves for bodies having greatest strength lie entirely between the full line curves, that is they follow approximately the course of the parabola. In series 5, Fig. 15, it is seen that all curves lie above Fullers parabola, and strength decreases as the parabola is approached. For bodies which contain all the sizes, the maximum strength curve is approximately the curve designated "maximum."

In concluding the discussion of the drying properties there are two phenomena to be explained. First, porosity of bodies in series 1, 2, and 3 increases because the larger sizes are more dense than an equal weight of packed smaller sizes; also the ratio of sizes shows that the voids are increased by the mixture of sizes. In series 4 the particles are so proportioned that the voids are decreased, and the porosity is less. Second; strength


TRANS. AM. CER. SOC. VOL. XIX
FIG. 12.
KIRKPATRICK
MODULUS OF RUPTURE - LBS. PER SQ. IN.
SURFACE FACTOR OF GROG
Relation between Surface Factor and Modulus of Rupture of Raw Bodies

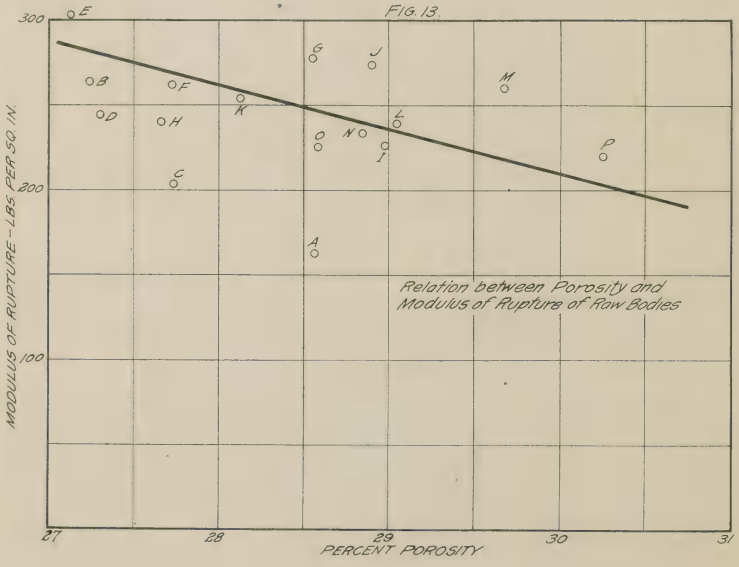


FIG. 13.
MODULUS OF RUPTURE - LBS. PER SQ. IN.
PERCENT POROSITY
Relation between Porosity and Modulus of Rupture of Raw Bodies

increases in series 1, 2, and 3 with increase of porosity. This is due to lack of bond and of contact between clay and grog, which causes small cracks which decrease in size with decrease in size of grog. In series 4 no cracks appear, bond is good, and strength increases with decrease of porosity.

Properties in the Burned State. Figures 16 to 20 show the relation between grog composition and modulus of rupture of bodies burned to cone 14. Table III gives moduli of rupture and Table IV porosities of bodies burned to cone 12.

In series 1 to 4 the modulus of rupture at cone 12 bears an approximate relation to porosity. The strength-porosity curve (Fig. 21) consists of two parts. From body 1A (4-8 grog) to bodies in series 3 (12-80 grog) strength increases with increase of porosity, due to small cracks developed in drying and not healing in burning. In series 4 (20-dust grog) and part of series 3, strength decreases with increase in porosity, the degree of vitrification being the governing factor. In series 5 (4-dust grog), there is no relation between porosity and modulus of rupture. Hence, for bodies containing grog of different sizes, porosity may give entirely wrong indications of strength.

Surface factor, however, does afford an accurate means of judging the strength of such bodies. In Figs. 22 and 23 surface factor of the grog portion of the bodies is plotted against modulus of rupture. The curves are of parabolic form in the lower portion and are straight lines in the upper portion. The relation is more exact in series 1 to 4 than in series 5. This is due to the latter containing comparatively large particles which are not dissolved by the clay to anywhere near the same extent as are the small particles.

Quenching Tests from 600°C. The results of these tests are presented in Table V and in Fig. 24. Bodies retaining the greatest percentage of strength were those in series 2, these of course overlapping certain portions of series 1 and 3. Bodies containing 8-40 mesh grog in the proper proportions withstood the treatment best, having values from 50 to 60 percent strength retained. The bodies in series 5 nearly all retained a smaller percentage of strength than those in series 2.

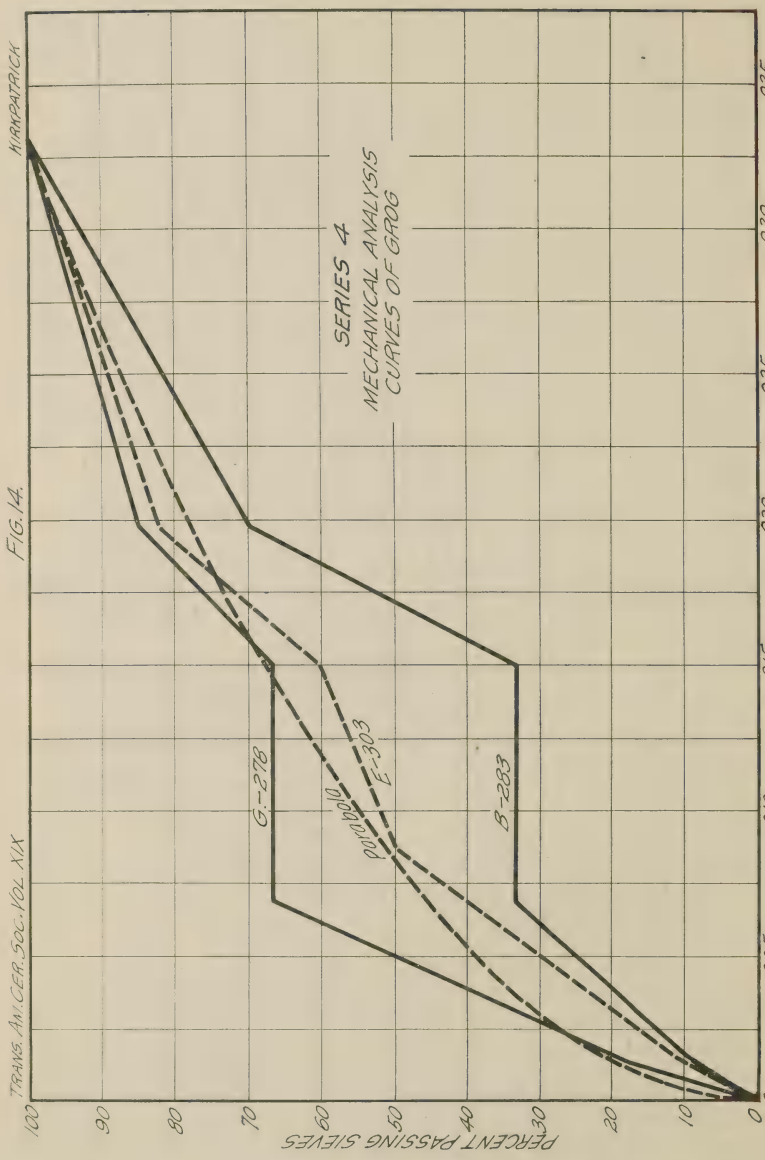

KIRKPATRICK
SERIES 4
MECHANICAL ANALYSIS
CURVES OF GROG
G-278
E-303
B-283
PERCENT PASSING SIEVES
NOMINAL SIZE OF OPENINGS IN SIEVES IN INCHES
0
10
20
30
40
50
60
70
80
90
100
.005
.010
.015
.020
.025
.030
.035

FIG. 14.

TABLE III — MODULUS OF RUPTURE OF BODIES BURNED TO CONE 12

SERIES	MODULUS OF RUPTURE				
	1	2	3	4	5
No.					
A	529	716	925	1467	749
B	687	1000	1428	2400	1548
C	549	742	1110	1628	1247
D	589	935	1353	2074	1624
E	660	1167	1623	2518	1954
F	659	966	1439	2300	1861
G	766	1218	1763	2815	2296
H	749	1158	1859	2400	2158
I	618	923	1300	1915	1656
J	784	1219	1953	2863	2617
K	684	1210	1823	2417	2632
L	705	1100	1496	2208	2135
M	925	1467	1866	3007	3007
N	923	1300	1915	2808	3198
O	742	1110	1628	2268	2744
P	716	925	1467	1866	2200

TABLE IV — POROSITY OF BODIES BURNED TO CONE 12

SERIES	1	2	3	4	5
No.					
A	19.8	22.8	24.0	25.1	22.5
B	21.7	22.5	24.3	22.8	22.0
C	20.5	23.0	25.0	25.2	22.7
D	21.5	22.8	24.1	23.1	21.0
E	22.3	23.5	24.6	22.1	21.9
F	21.8	24.2	24.3	23.9	22.7
G	22.9	23.6	24.5	22.5	21.9
H	22.5	24.4	24.3	23.6	20.3
I	21.4	23.6	25.1	26.1	23.6
J	23.6	24.5	24.6	23.2	21.0
K	22.3	24.7	24.7	24.0	21.6
L	22.6	23.9	25.1	24.3	21.4
M	24.0	25.1	26.5	24.7	24.7
N	23.6	25.0	26.1	24.0	22.6
O	23.0	25.0	25.2	23.4	22.6
P	22.8	24.0	25.1	26.5	25.7

Quenching Tests from 1000°C. The results from these tests are given in Table VI and in Fig. 24. The most resistant bodies were found in series 1 and 2 (4-40 mesh grog). In Fig. 24 surface factor is plotted against results of quenching tests. The results for 600°C. agree fairly well with those for 1000°C. In general, increase of surface factor causes decrease in resistance to sudden heating and cooling. The first part of the curve (from 1A to 1D, etc.) indicates that the largest size grog was too large for the briquettes used causing spalling and destruction of the body. Four standard size fire brick containing small size grog (through 20 mesh or finer) were heated with the briquettes in the 1000° C. quenching tests. These cracked in two on the average at the seventh treatment. Two fire brick containing large size grog (about ¼ inch) cracked or spalled on the average upon the 25th treatment. Hence, standard size brick of the compositions used in this investigation would withstand, on account of their dimensions, two or three times the number of treatments undergone by the briquettes.

SUMMARY OF RESULTS

In order to obtain fire clay bodies having highest moduli of rupture in the raw dried state, two conditions are necessary: (1) The grog must not be too large so that it forms cracks, or planes of weakness, due to lack of the clay to bind such large particles together perfectly. (2) The grog must be so proportioned that the smaller sizes fill the voids between the larger particles giving maximum density and strength. These conditions are met in series 4, the grog portions of the strongest bodies having the following limits of composition:

25	to $66^2/_3$	percent	20-40 grog
0	to 25	percent	40-80 grog
$33^1/_3$	to $66^2/_3$	percent	80-dust

For all bodies used, the modulus of rupture in the burned state was found to increase with the surface factor, the relation being represented by a curve whose lower portion is parabolic in form and whose upper portion is a straight line. The rate of increase of strength increased with the temperature of

TABLE V — PERCENT OF STRENGTH RETAINED BY BODIES AFTER QUENCHING FROM 600°C. FIVE TIMES

SERIES	1	2	3	4	5
No.					
A	34.2	46.3	50.0	53.4	46.6
B	48.5	54.8	42.5	39.6	40.8
C	38.8	50.4	50.6	48.4	51.7
D	40.6	51.2	48.7	36.4	47.9
E	43.9	47.3	45.9	37.8	42.4
F	48.5	49.5	47.0	36.9	43.0
G	46.5	49.2	39.7	32.4	30.5
H	46.6	54.5	41.4	36.8	49.2
I	41.4	50.0	48.0	41.8	49.4
J	50.1	57.6	38.0	37.5	27.5
K	55.0	53.2	42.5	37.2	35.2
L	58.3	50.0	46.9	36.6	46.4
M	50.0	53.4	40.0	14.3	14.3
N	50.2	48.0	41.8	31.4	18.5
O	50.4	50.6	48.4	37.8	34.0
P	46.3	50.0	53.4	40.0	55.3

TABLE VI. — NUMBER OF QUENCHING TREATMENTS WITHSTOOD FROM TEMPERATURE OF 1000°C

SERIES	1	2	3	4	5
No.					
A	8	11	10	8	12
B	9	10	10	5	4
C	11	10	10	8	5
D	12	10	9	7	3
E	12	9	10	5	3
F	12	11	9	5	3
G	10	8	8	3	2
H	12	11	10	5	2
I	11	10	9	7	3
J	14	9	4	4	2
K	13	10	4	5	2
L	12	12	6	4	3
M	10	8	5	2	2
N	10	9	7	3	2
O	10	10	8	4	2
P	11	10	8	5	3

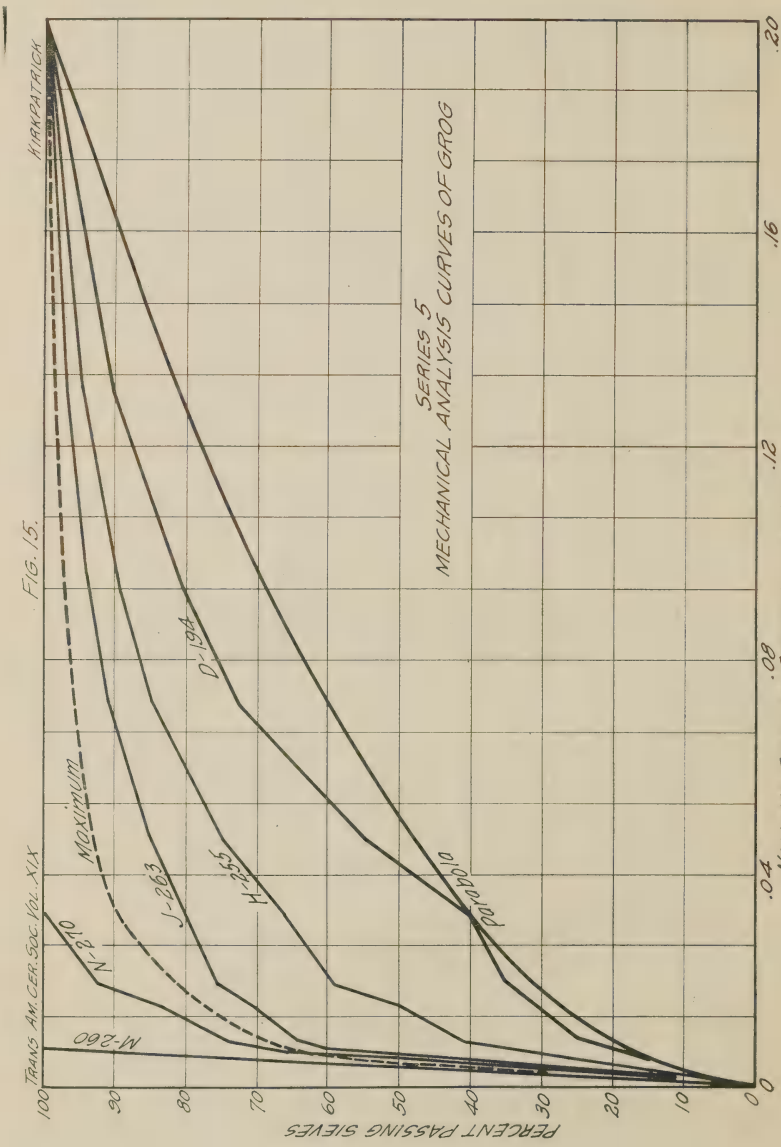

KIRKPATRICK
TRANS. AM. CER. SOC. VOL. XIX
SERIES 5
MECHANICAL ANALYSIS CURVES OF GROG
MAXIMUM
M-260
N-270
J-363
H-255
O-194
PERCENT PASSING SIEVES
NOMINAL SIZE OF OPENINGS IN SIEVES IN INCHES
100
90
80
70
60
50
40
30
20
10
0
.20
.16
.12
.08
.04
0

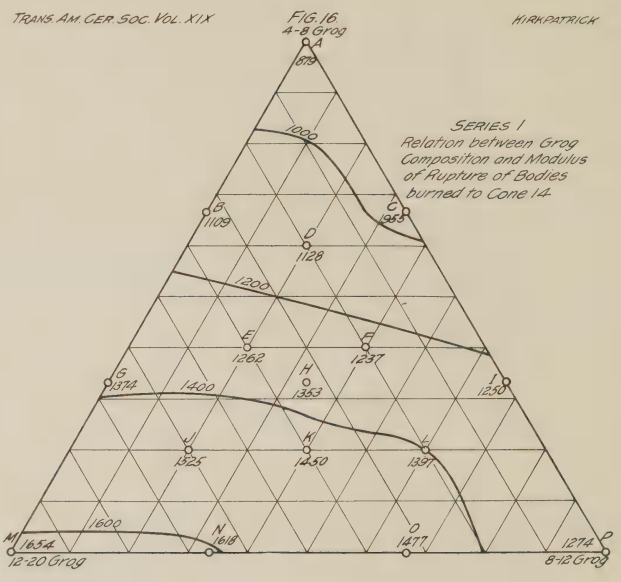
FIG. 15.

burning. An exact relation was not found between strength and porosity for all bodies used. The strongest bodies were those in series 4 (20-dust grog). No relation was found between strength in the raw state and in the burned state. In the quenching tests from 600°C. and 1000°C., mixtures of larger sizes of grog proved best.

Although the laboratory investigation has not been supplemented by practical work, it may be of value to indicate a few methods of application. Grog for glass pots and similar bodies may contain too much fine or intermediate sized material causing low strength and cracking in drying. The composition of 20 mesh grog may be corrected by reference to Fig. 9. The best bodies have compositions within the maximum strength area described above. These had moduli of rupture of from 275 to 300 pounds per square inch in the raw state, and from 3500 to 4400 pounds per square inch in the burned state. Point "X" in Fig. 9 represents the composition shown by the parabola of Fig. 14. Point "Y" represents closely the composition of grog furnished by the Harbison-Walker Refractories Company of Pittsburgh, Pa., for the investigation of Bleininger and Schurecht on European plastic fire clays.[9] This shows that grog may be ground to give the proportions for maximum strength. Where screening into separate sizes and recombining is uneconomical, this may be accomplished by control of the conditions of grinding, as time, size of openings in screen plates, pressure, etc.

The question of sagger loss is a serious one in many plants. A review of German, French, and American practice discloses many different methods of sagger manufacture. Composition is much varied. The clays used are of all grades from kaolins to shales and possess all degrees of plasticity and refractoriness, necessitating the use of various percentages of grog. The latter varies in composition from the best flint fire clay to used bats of various degrees of disintegration.

In American practice grog for saggers is used all through 3 to 6 mesh screens, while German and French manufacturers separate it into two or three sizes, classified roughly as fine, medium, and coarse. There is a wide variation in the propor-


TRANS. AM. CER. SOC. VOL. XIX
FIG. 16
4-8 Grog
KIRKPATRICK
A
1879
1000
SERIES 1
Relation between Grog Composition and Modulus of Rupture of Bodies burned to Cone 14
B
1109
C
1945
D
1128
1200
E
1262
F
1237
G
1374
1400
H
1353
I
1250
J
1525
K
1450
L
1391
1600
M
1654
12-20 Grog
N
1618
O
1477
P
1274
8-12 Grog

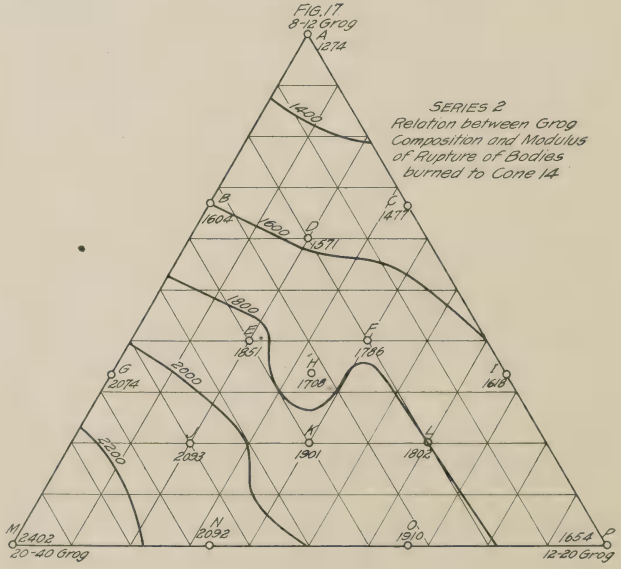
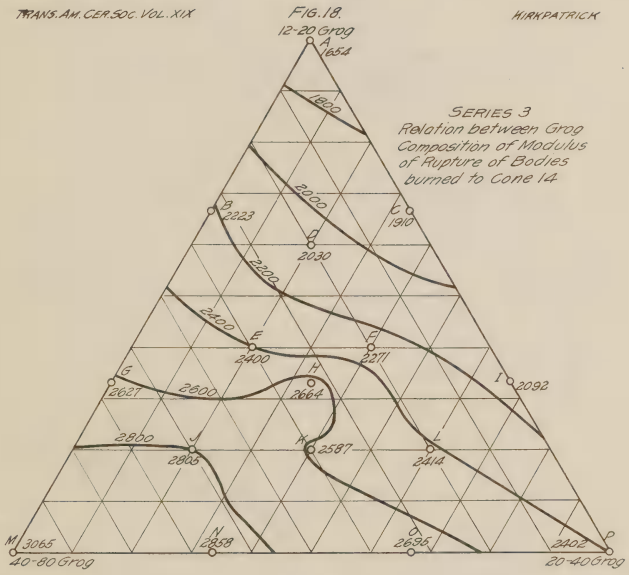


FIG. 17
8-12 Grog
A
1274
1400
SERIES 2
Relation between Grog Composition and Modulus of Rupture of Bodies burned to Cone 14
B
1602
1600
C
1477
D
1571
1800
E
1857
F
1706
G
2074
2000
H
1708
I
1618
2200
J
2093
K
1901
L
1802
M
2402
20-40 Grog
N
2092
O
1910
P
1654
12-20 Grog

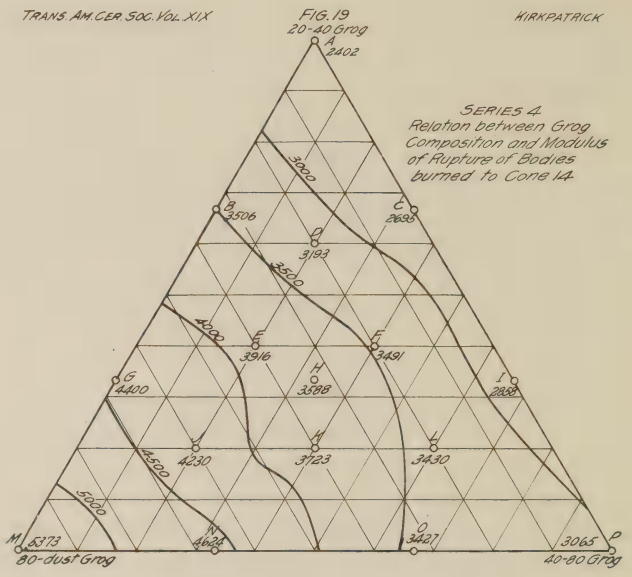
tions of sizes used, there being apparently no fundamental basis of reason for compounding the mixtures. In general, the larger the sagger the larger are the sizes of grog used. In many instances additions of sawdust, coal powder, quartz sand, alumina, or other materials are added to the mixture to increase porosity or refractoriness. Many ingenious methods have been devised for shaping, molding, and reinforcing saggers. Machine-made saggers are found to be more satisfactory than hand-made.



The temperature of burning varies much and has considerable influence upon the length of life of the sagger.

In attempting to apply the results of this investigation to saggers, the size of grog must be assumed to be the governing factor. Otherwise, the application might go far astray. Other factors having been eliminated the grog compositions given in Table VII seem best suited for saggers having walls and bottoms one inch in thickness.

[9] *U. S. Bureau of Standards Technologic Paper No.* 79, p. 19.


TRANS. AM. CER. SOC. VOL. XIX
FIG. 19
20-40 Grog
KIRKPATRICK
A
2402
SERIES 4
Relation between Grog Composition and Modulus of Rupture of Bodies burned to Cone 14
3000
B
3506
C
2695
D
3193
3500
4000
E
3916
F
3491
G
4400
H
3898
I
2888
4230
K
3123
L
3430
4500
5000
M
5373
N
4624
O
3427
3065
P
80-dust Grog
40-80 Grog

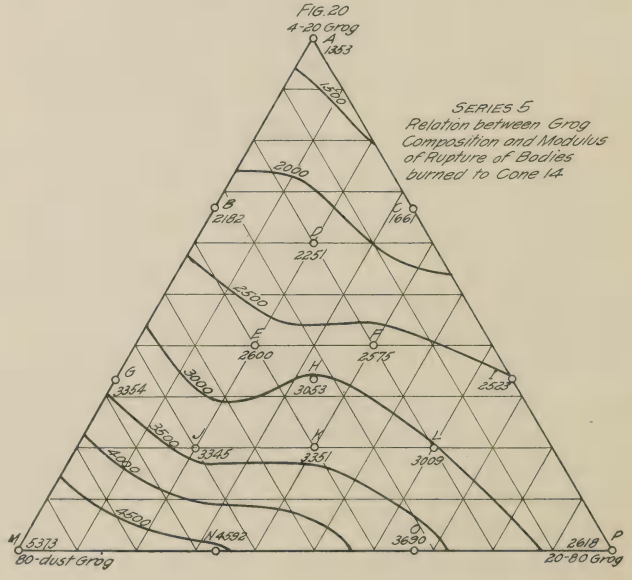


FIG. 20
4-20 Grog
A
1283
SERIES 5
Relation between Grog Composition and Modulus of Rupture of Bodies burned to Cone 14
1500
2000
B
2182
C
1661
D
2251
2500
E
2600
F
2575
G
3354
3000
H
3053
I
2523
3500
J
3345
K
3351
L
3009
4000
4500
M
5373
N
4592
O
3690
P
2618
80-dust Grog
20-80 Grog

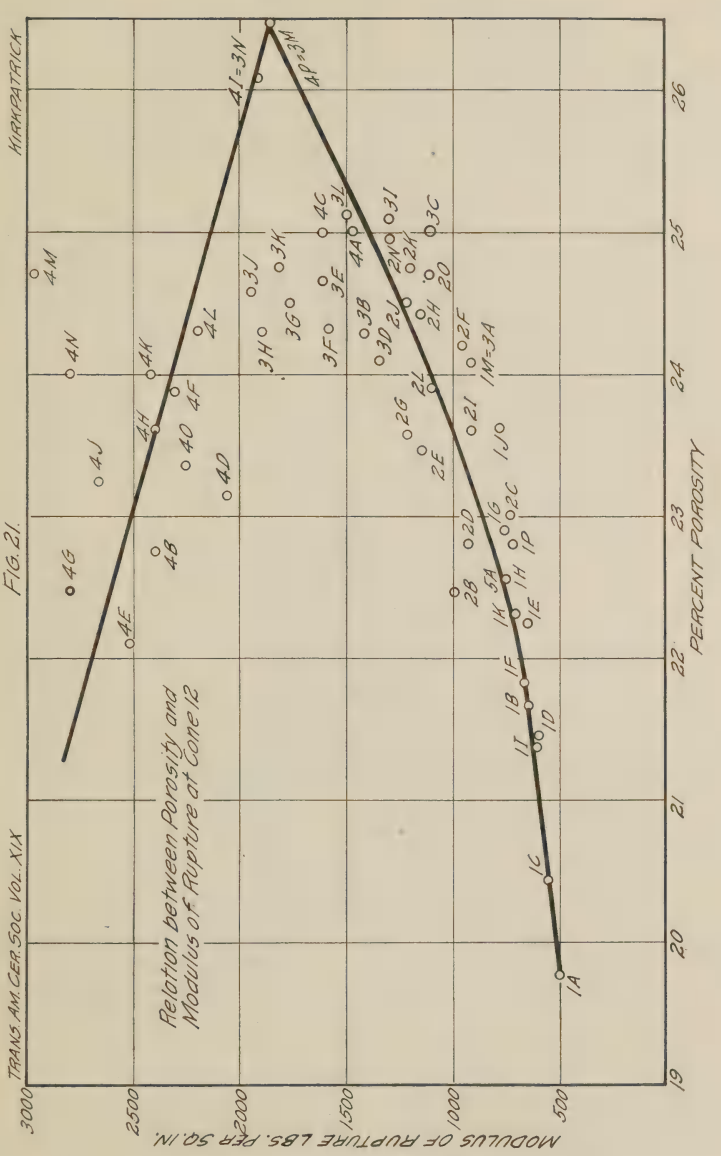

Relation between Porosity and Modulus of Rupture at Cone 12
MODULUS OF RUPTURE LBS. PER SQ. IN.
PERCENT POROSITY
TRANS AM CER SOC VOL. XIX
KIRKPATRICK
3000
2500
2000
1500
1000
500
19
20
21
22
23
24
25
26

FIG. 21.

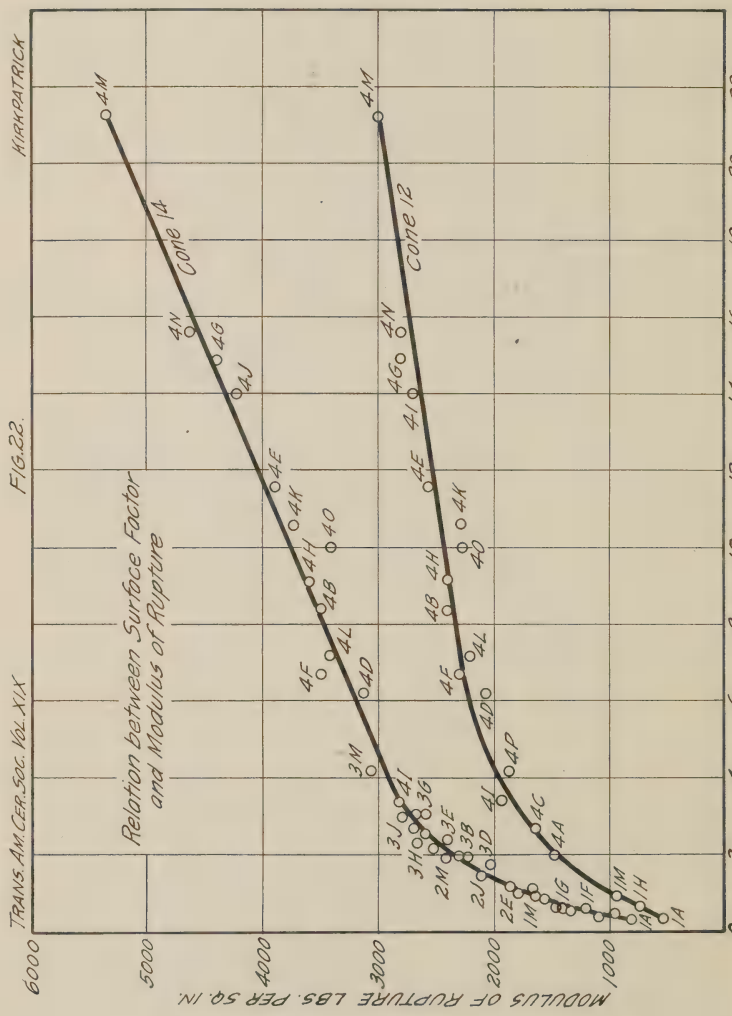

KIRKPATRICK
FIG. 22.
TRANS. AM. CER. SOC. VOL. XIX
Relation between Surface Factor and Modulus of Rupture
Cone 14
Cone 12
4M
4N
4G
4J
4E
4K
4H
4O
4B
4L
4F
4D
3M
4I
3J
3H
3G
3E
2M
3F
2J
3D
2E
1M
1G
1F
1M
1H
1A
1A
SURFACE FACTOR OF GROG
0
2
4
6
8
10
12
14
16
18
20
22
MODULUS OF RUPTURE LBS. PER SQ. IN.
6000
5000
4000
3000
2000
1000

TABLE VII

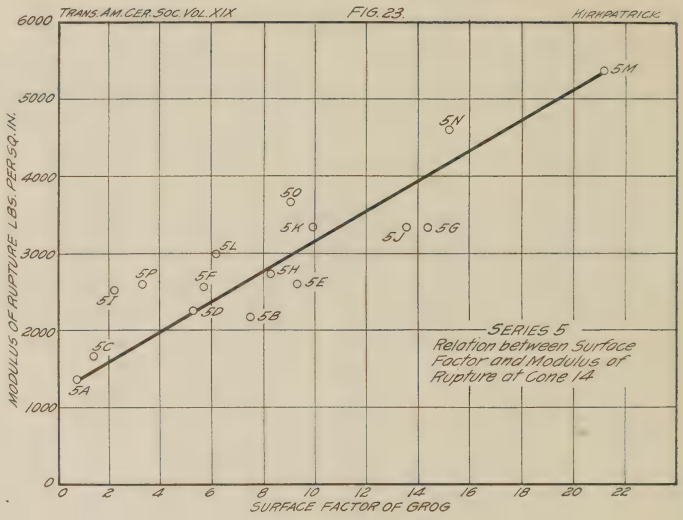
NO.	COMPOSITION OF GROG MESH OF SIEVE					PERCENT STRENGTH RETAINED 600°C. TEST	QUENCHING TREATMENTS WITHSTOOD 1000°C. TEST	MODULUS OF RUPTURE RAW STATE	MODULUS OF RUPTURE CONE 14
	4-8	8-12	12-20	20-40	40-80				
				Group I.					
1K	20	40	40	..	..	55.0	13	142	1450
1L	20	60	20	..	..	58.3	12	136	1525
2J	..	20	20	60	..	57.6	9	180	2093
2H	..	33⅓	33⅓	33⅓	..	54.5	11	162	1901
				Group II.					
3A	..	..	100	..	..	50.0	10	147	1654
3C	..	..	66⅔	33⅓	..	50.6	10	167	1910
3D	..	..	60	20	20	48.7	9	208	2030
3F	..	..	40	40	20	47.0	9	195	2271
3I	..	..	33⅓	66⅔	..	48.0	9	174	2092
3L	..	..	20	60	20	46.9	6	198	2414
3O	..	..	..	66⅔	33⅓	48.4	8	203	2695
3P	..	..	..	100	..	53.4	8	183	2402

Group I is recommended where resistance to repeated heating and cooling is desired more than strength. In Group II, resistance to repeated heating is sacrificed to obtain bodies of greater strength. The results show that both very large and very fine grog are undesirable in sagger bodies of the compositions used in this investigation.

In conclusion, the writer desires to express his thanks to Prof. A. V. Bleininger, Prof. G. H. Brown, and Mr. H. G. Schurecht for their co-operation and assistance in the laboratory work and in the theoretical discussion of the results.

DISCUSSION

Mr. Creighton: Mr. Kirkpatrick has given us some very important information. It seems to me that it is too much to really digest in this brief period, but there is one very important thing regarding the result of this work, which it seems to me


TRANS. AM. CER. SOC. VOL. XIX
FIG. 23.
KIRKPATRICK
MODULUS OF RUPTURE LBS. PER SQ. IN.
SURFACE FACTOR OF GROG
SERIES 5
Relation between Surface Factor and Modulus of Rupture at Cone 14

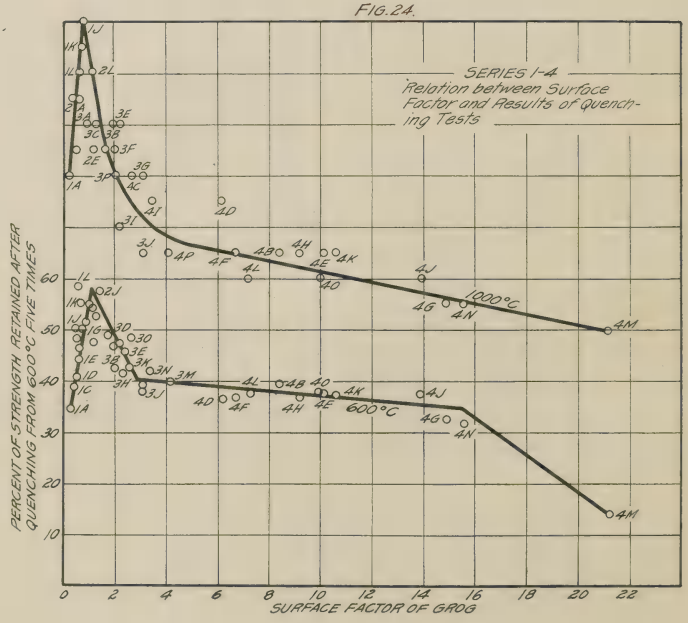


FIG. 24.
PERCENT OF STRENGTH RETAINED AFTER QUENCHING FROM 600°C FIVE TIMES
SURFACE FACTOR OF GROG
SERIES 1-4
Relation between Surface Factor and Results of Quenching Tests
1000°C
600°C

would help us and that is the choice or criterion of tests, whether they might be compression or tension or shear. You have chosen a certain test for this, and no doubt there is a very good reason for it. I am interested in the matter because I am just going through a stage in the development of some cement in which the compression test shows almost nothing at all relative to the factors I am investigating, and I would like to know if Mr. Kirkpatrick has gone through this from that standpoint, and has chosen this particular method of test to bring out something in particular?

Mr. Kirkpatrick: We did not make determinations to find out which would be the better test of strength. The modulus of rupture of course ought to be made on pieces which are comparatively long in regard to their cross section, and in regard to clay products, I do not think it has ever been proven that the laws which apply to steel and to other metals do apply accurately to our ceramic bodies. The modulus of rupture test has been considered to give a very good idea, of the strength since fluxural strength is the resultant of compressive, tensile and shearing strength.

Mr. Creighton: Would not the test under tension give a still better indication of the strength of this material than would be given by the test made, although that is about half way between the tension and the compression? I have a feeling that the compression test gives almost no indication of the coherence of the material and its real strength.

Mr. Kirkpatrick: That is entirely possible, but it remains to be proven. For fire-clay bodies I think that before we could say anything definite upon that point, it would be necessary to actually make such determinations.

Mr. Pence: I am impressed with the practical nature of the modulus of rupture test here, because my observation in the failure of sagger bodies to which this is particularly applicable, is that these failures come about through strains which are brought upon the sagger in much the same way as this modulus of rupture would be obtained, and these failures occur not only in the kiln, but they occur in the general handling of the saggers and piling them up, say 10 high. There will always

be a number of them broken through strain brought about by irregular distribution of pressure upon the sagger, causing it to fail about the same way as you have obtained this modulus of rupture. I would like to ask if you are able to state, in conclusion, whether you would recommend, for fire clay body purposes, the large grog rather than the fine grog, or any definite mixture of large grog and fine grog in the compounding of sagger bodies?

Mr. Kirkpatrick: If one would discuss the entire question, it would take up too much time, because different bodies require different compositions, but as to the sagger bodies, I would say it would be necessary to strike a mean between certain properties. You cannot get an ideal body, and all you can do is to come as near to it as possible. We could choose a body sufficiently strong in the dry state and sufficiently strong in the burned state, and which resisted repeated heating and cooling to a high degree.

Mr. Pence: The reason I asked that question is that my experience has been contrary to that offered by some who have said they found it necessary to eliminate fine grog and use only coarse grog, a quarter of an inch and upwards. My experience has been that I found a better sagger body from an incorporation of the fine grog and not such a large proportion of the coarse.

Mr. Geo. Brown: I think that this was due in part to the development of the fine hair cracks caused by the large particles of grog, and that by reducing the size of the grog the number of these cracks was decreased hence increasing the strength of the mixture.

Mr. Plusch: What size test piece did you use?

Mr. Kirkpatrick: I should have stated that in the first place; one inch by one by seven inches for the drying test, with a six inch span for the raw bodies; the broken half pieces were used with 2 inch span for the burned bodies.

Mr. Plusch: And you got the same modulus of rupture from all coarse and all fine grog?

Mr. Kirkpatrick: We obtain comparative results.

Mr. Plusch: In using coarse grog, the surface factor would be less than fine grog, consequently you would have less clay binder.

Mr. Kirkpatrick: We have the same clay binder by weight.

Mr. Plusch: But not physically. Looking at it from a practical standpoint, it seems to me that it would be very essential to find the right sized test piece for each size of grog used; do you get my point on that?

Mr. Kirkpatrick: Yes, from the entire work I should say that the size of the test piece used was entirely appropriate except for the bodies in series 1, that is those which contain any of 4-8 sized grog.

Mr. Plusch: And that is the body which most of us who are practically interested in this line are using. I think it is the experience of most of us that the coarser grog gives us the best results. In fact answering Mr. Pence's question, a sagger body made, eliminating the fine and using coarse grog on the same basis you are using 50 percent of each as compared to one using fine grog you will find that there is no question as to how much longer the coarse grog body will stand up. Another thing, I think it would be well to suggest to the Bureau of Standard, that in further experiments along this line, the modulus of rupture be taken not only after the first burn, but to see how many burns the piece will take, and what the modulus of rupture is after 1, 2, 3, 4 and successive burns of the kiln.

Mr. Kirkpatrick: Yes, that is very good idea; we would have done that had we had time.

DISCUSSION SUBMITTED AFTER READING PAPER

Mr. Pence: Since reading the paper, I note that the proportion of grog sizes that I have found satisfactory, corresponds to those recommended by Mr. Kirkpatrick in Table VII Group I.

Mr. Kirkpatrick: It has been shown by Bleininger and Howat (*Trans. Amer. Ceramic Society XVI*, p. 275) that modulus of rupture gives more uniform results for strength of raw clay bodies than do compressive or tensile strength. Other work has shown this to be true for burned bodies. This might be expected since bars under transverse load are subject to forces of shear, tension and compression and the modulus of rupture or flexural strength results from a combination of these three forces. For the purpose of the present investigation the flexural strength

gives a better all around idea of strength than is obtained in any other manner.

In regard to the size of test pieces used, the results themselves determine whether it was suitable or not. The 1 in. by 1 in. by 7 in. bars proved satisfactory for all tests except in the quenching tests for some bodies containing 4-8 grog. The work would have to be duplicated a number of times if the effect of size of test pieces were determined.

As stated under "Summary of Results" there is no agreement among sagger users as to the best size of grog. This varies with different conditions in the manufacture and use of saggers. Considering the size of grog as the governing factor, the best bodies for saggers of 1 inch sides and bottoms proved to be those containing 4-80 grog of the proper proportion of sizes.

THE PRACTICAL APPLICATION OF BRISTOL GLAZES COMPOUNDED ON THE EUTECTIC BASIS

BY ARTHUR S. WATTS

In order to prove the practical application of the Bristol glaze study which I reported last year, three glazes were chosen from the area designated as the eutectic area, and these were tested in commercial operations over as broad a range of temperature as was possible. The glazes tested were as follows:

A

$$\left.\begin{matrix}.4\ K_2O \\ .25\ CaO \\ .35\ ZnO\end{matrix}\right\} .6\ Al_2O_3 - 3.47\ SiO_2$$

Feldspar	60.87
Whiting	6.25
Zinc oxide	7.76
China clay	7.06
Ball clay	7.06
Flint	11.00
	100.00

B

$$\left.\begin{matrix}.35\ K_2O \\ .20\ CaO \\ .45\ ZnO\end{matrix}\right\} .565\ Al_2O_3 - 3.10\ SiO_2$$

Feldspar	57.07
Whiting	5.86
Zinc oxide	10.69
China clay	8.15
Ball clay	8.15
Flint	10.08
	100.00

C

$$\left.\begin{matrix} .3\ K_2O \\ .3\ CaO \\ .4\ ZnO \end{matrix}\right\} .534\ Al_2O_3 - 3.00\ SiO_2$$

Feldspar	50.10
Whiting	9.01
Zinc oxide	9.73
China clay	9.07
Ball clay	9.07
Flint	13.02
	100.00

These were all applied at a density of 22 ounces per pint.

Over a range from cone 3 to cone 14, these glazes have proven practical. Some difficulty has arisen, due to deficient mixing, but whenever properly ground a smooth bright coat has resulted. A wide variety of clays has been glazed with apparently equal success. The variation in ZnO content is apparent in the whiteness of the different glazes, but even at cone 10 the opacity of all three is sufficient to satisfactorily mask the color of a buff clay. At cones 12 and 14 the glazes were used on electrical porcelain and showed almost as much opacity as at cone 10. At cones 3, 4 and 5 these glazes all produce fine smooth enamels, suitable for novelty pottery, and cooking ware.

In no case has any evidence of crazing been noted, and when applied at a density of less than 23 oz. per pint, no tendency to crawl is apparent. These glazes will not heal over if once their surface is broken; and if the ware has loose dust on the surface, pin-holing will occur. But, if employed as Bristol glazes are ordinarily employed, the color and texture of these glazes was found to remain uniform over a far greater range than commercial operations require, and the glazes are, therefore, recommended to the consideration of users of Bristol glazes.

THE RELATION BETWEEN THE FUSION POINT AND THE COMPOSITION OF REFRACTORY CLAYS

BY R. J. MONTGOMERY AND C. E. FULTON.

The purpose of this paper is to present a summary of the test results obtained in quite a number of refractory clays and a few silica-clay mixtures giving compositions varying from 1 to 40 percent alumina. This summary shows the relative influence of silica, alumina and the basic fluxes on the fusion point or what might be more properly called the softening point of refractory clays.

Results of Tests. In connection with certain commercial work a large number of refractory clays were tested. These clays include practically all the plastic refractory types, such as kaolins, ball clays, bond clays (both American and European) and fire clays; fifty-seven in all. These are practically all very fine grained, and in most cases at least 95 percent would pass a 200 mesh screen when mixed with water in slip form. In order to extend the limits of composition somewhat further a number of silica-clay mixtures are also included. These mixtures are somewhat coarser; all will pass a 20 mesh screen and 35 to 40 percent will pass thru a 200 mesh screen, Tyler Standard. The results on twenty-seven commercial samples are recorded, two plastic clays of quite different character being used as the base. Owing to the fact that only two different clays are introduced, only the general indication as shown by these can be considered. The Table I gives the part of the analysis used, the softening point and other data used in this paper.

Under the head of calculated values, those for alumina and silica given in columns 5 and 6 were obtained by adding the columns 2 and 3 together and calculating the percent of each or the ratio of silica to alumina based upon 100. In Figure 1 the values are plotted against the fusion cone of the clay or silica-clay mixture. The silica-alumina eutectic curve as given

TABLE I

NO.	ANALYSIS			CALCULATED VALUES			FUSION	CONES BELOW CURVE
	SiO_2	Al_2O_3	FLUXES	SiO_2	Al_2O_3	FLUXES		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	percent	*percent*	*percent*	*percent*	*percent*	*percent*	*cone*	
1	47.50	35.80	3.53	57.0	43.0	4.07	33—	¼
2	42.97	39.51	0.70	52.1	47.9	0.85	33+	*
3	57.11	28.53	3.03	66.2	33.8	3.42	30+	2¾
4	76.45	14.60	3.35	83.9	16.1	3.54	26	3¼
5	47.40	36.06	5.51	56.8	43.2	6.21	32+	2½
7	50.58	33.07	5.50	60.4	39.6	6.17	31	3
8	66.85	18.77	4.87	78.2	21.8	5.38	26+	4½
9	73.07	15.93	5.43	82.0	18.0	5.77	26—	4¼
10	58.11	26.28	5.89	68.8	31.2	6.53	29	3½
11	64.08	21.35	6.69	75.0	25.0	7.27	26—	5½
12	57.99	22.26	9.59	72.2	27.8	10.66	15+	13¾
13	51.37	31.38	3.69	62.1	37.9	4.27	32—	2
14	63.38	22.31	5.77	74.1	25.9	6.32	28	3½
15	73.14	18.27	3.45	80.1	19.9	3.64	28	2½
16	47.66	35.11	3.39	57.6	42.4	3.94	33—	1¾
17	73.31	15.18	2.95	82.6	17.4	3.23	27+	2¼
18	54.42	30.47	4.18	64.1	35.9	4.70	31+	2
19	45.73	37.80	3.67	54.7	45.3	4.22	34—	1½
20	57.05	27.31	8.13	67.6	32.4	8.80	20	10
21	58.67	26.96	6.87	68.4	31.6	7.42	29	3½
22	51.89	30.40	2.45	63.0	37.0	2.90	32+	1¼
23	58.71	28.03	6.04	67.6	32.4	6.52	28	4¾
24	53.38	29.86	6.17	64.1	35.9	6.89	30	3¼
25	45.23	37.95	4.77	54.3	45.7	5.42	33	2
26	47.42	37.09	2.11	56.0	44.0	2.44	33+	1½
27	54.58	26.76	8.29	67.2	32.8	9.25	26—	7
28	46.46	31.32	4.29	59.7	40.3	5.23	33½	¾
29	57.34	28.50	2.40	66.8	33.2	2.72	32½	½
30	56.11	28.21	3.51	66.5	33.5	4.00	31½	1½
31	57.47	29.16	3.52	66.3	33.7	3.90	31—	2
32	68.41	21.54	2.86	76.1	23.9	3.08	30—	1½
33	53.87	29.12	7.17	65.0	35.0	7.94	28	5
34	59.22	30.07	3.76	66.2	33.8	4.00	32	1
35	71.51	18.86	3.51	79.2	20.8	3.74	27+	3¼
36	54.72	30.35	4.28	64.2	35.8	4.80	32—	1½
37	44.01	40.80	1.37	52.0	48.0	1.59	33+	*
38	51.80	32.59	3.46	61.5	38.5	3.94	32	1¾
39	69.27	21.07	3.14	76.7	23.3	3.36	27	4
40	47.04	38.04	.96	55.2	44.8	1.10	33½	½†
41	46.68	37.96	1.69	55.1	44.9	1.96	33½	½†
42	47.27	34.85	3.95	57.6	42.4	4.59	33+	1¼
43	48.72	31.89	5.23	60.3	39.7	6.10	33	1
44	53.87	30.83	3.84	63.7	36.3	4.34	33—	¾
45	61.02	26.32	3.86	70.0	30.0	4.23	31—	1½

* Fusion cone above 32, but not definite enough to obtain value.
† Fusion cone above 33½ — Drop of ½ cone below curve is very nearly correct.

TABLE I — Concluded

NO.	ANALYSIS			CALCULATED VALUES			FUSION	CONES BELOW CURVE
	SiO_2	Al_2O_3	FLUXES	SiO_2	Al_2O_3	FLUXES		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	percent	*percent*	*percent*	*percent*	*percent*	*percent*	*cone*	
46	64.72	21.51	3.70	75.1	24.9	4.12	30+	1¼
47	60.60	25.98	2.71	69.9	30.1	3.04	30+	2
48	47.33	36.44	2.08	56.5	43.5	2.43	33½	1¼
49	58.96	26.95	2.97	68.6	31.4	3.35	31+	1½
50	68.91	20.53	3.13	77.2	22.8	3.38	30½	½
51	52.72	32.37	2.96	61.8	38.2	3.36	33	¾
52	56.32	28.72	3.94	66.2	33.8	4.44	32	1
53	50.77	34.68	5.09	59.6	40.4	5.62	33—	1½
54	44.33	35.36	3.33	55.7	44.3	4.00	33+	1¾
55	44.92	38.43	2.58	53.9	46.1	3.00	33½	1¾
56	47.15	35.96	3.02	56.7	43.3	3.51	34	¾
57	66.35	18.58	5.63	78.3	21.7	6.22	26	3¾

Silica — Clay Mixtures

	percent	*percent*	*percent*	*percent*	*percent*	*percent*	*cone*	
1	83.30	11.68	....	87.8	12.2	....	28	¼
2	87.80	8.27	....	91.2	8.8	....	27	0
3	90.30	5.84	....	94.0	6.0	....	29	¼
4	90.71	5.50	....	94.3	5.7	....	28	1¼
5	92.0	5.18	....	94.7	5.3	....	30	0
6	91.44	5.76	....	93.9	6.1	....	29½	0
7	91.56	5.46	....	94.3	5.7	....	28	1¼
8	90.58	4.99	....	94.7	5.3	....	30	0
9	92.14	4.13	....	95.7	4.3	....	31	0
10	92.30	4.82	....	95.0	5.0	....	29½	½
11	92.50	4.75	....	95.0	5.0	....	29	1
12	91.64	4.86	....	94.7	5.3	....	29½	¼
13	94.16	3.80	....	96.2	3.8	....	29	1¾
15	94.16	2.12	....	97.6	2.4	....	30	1¾
16	94.30	1.32	....	98.5	1.5	....	31½	¾
17	93.58	1.54	....	98.3	1.7	....	32	¼
18	94.90	1.50	....	98.5	1.5	....	31	1¼
19	94.00	2.43	....	97.6	2.4	....	29½	2
20	93.00	1.03	....	98.7	1.3	....	31½	1
21	91.62	2.60	....	97.3	2.7	....	31½	0
22	92.96	3.73	....	96.1	3.9	....	30	¾
23	90.48	4.12	....	95.5	4.5	....	29½	1
24	92.00	4.85	....	95.0	5.0	....	30	0
25	88.30	8.27	....	91.3	8.7	....	26	0
26	87.16	8.65	....	90.9	9.1	....	27	1+
27	87.31	8.24	....	91.3	8.7	....	26	0
28	89.13	6.62	....	92.9	7.1	....	26½	¾

by Sosman[1] is also shown for comparison. A consideration of the sheet shows at once that the eutectic line is a boundary or indicates the limit of refractoriness that may be reached with a certain silica-alumina ratio. These data are given on the percent basis and not on the molecular equivalent or moleculer percent basis as the calculations on the percent basis are more simple and the scales used in plotting are better proportioned.

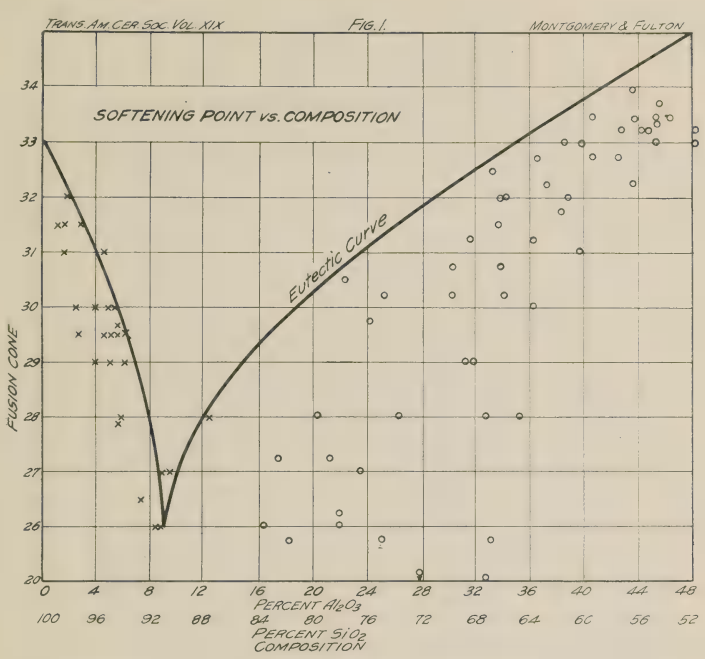
We can say quite definitely from Figure 1, that the analysis may show the limit of refractoriness of a clay, and that the silica-alumina ratio is the determining factor of fundamental importance.

The fusion point of many of the clays drops considerably below the eutectic line and is caused largely by the basic fluxes present as the fineness is very nearly the same in all cases. All clays that showed any considerable residue on 200 mesh are not included in this list. With the silica-clay mixtures the eutectic line is followed very closely. The cause of this will be discussed later.

In order to study the effect of the fluxes in the lowering of the softening point the number of cones reduction below the eutectic line was recorded in column 9 of Table I, and the actual percent of the fluxes, based on the dehydrated clay was calculated and recorded in column 7 of Table I. This was only done for the clays, as the variation of the fluxes in the silica-clay mixtures was very small. As was said before, only two clays were used as the bases of these mixtures, and the actual fusion point in no case fell more than two cones below the eutectic line.

In Figure 2 the relation between the percent fluxes present in the clays and the drop below the eutectic curve in cones is shown. A heavy line curve showing the average effect is given. While the general shape of the curve is unmistakable, the points are considerably bunched and indicate that some other factor of importance should be considered. As it is well known that the activity of fluxes is influenced by the silica-alumina ratio the clays were divided into four groups based on the alumina content as given in column 6, Table I, as follows:

[1] *Trans. Amer. Cer. Soc. XV*, p. 486.


TRANS. AM. CER. SOC. VOL. XIX
FIG. 1.
MONTGOMERY & FULTON
SOFTENING POINT vs. COMPOSITION
Eutectic Curve
FUSION CONE
34
33
32
31
30
29
28
27
26
20
0 4 8 12 16 20 24 28 32 36 40 44 48
PERCENT Al_2O_3
100 96 92 88 84 80 76 72 68 64 60 56 52
PERCENT SiO_2
COMPOSITION

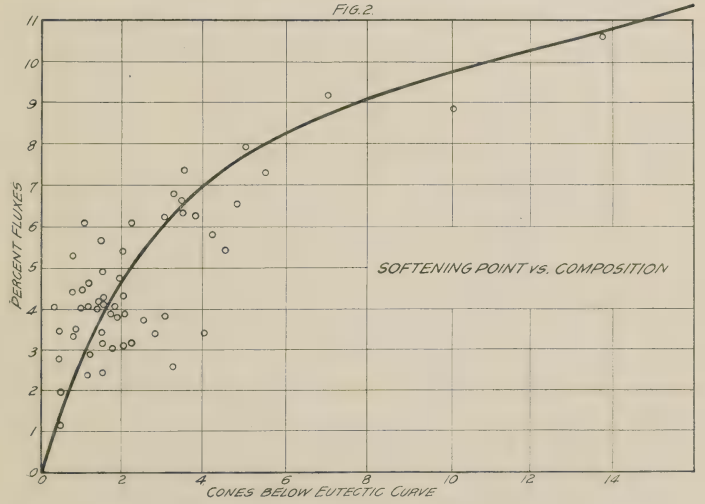


FIG. 2
PERCENT FLUXES
SOFTENING POINT vs. COMPOSITION
11
10
9
8
7
6
5
4
3
2
1
0
0 2 4 6 8 10 12 14
CONES BELOW EUTECTIC CURVE

Alumina 16 to 24 percent.
Alumina 24 to 32 percent.
Alumina 32 to 40 percent.
Alumina 40 to 48 percent.

The results were again plotted as shown in Figures 3-4-5-6. Unfortunately the points are not numerous enough in all four groups to establish the curve as well as could be desired, but the general curve as shown is unmistakable, and the increased fluxing effect of the same percent of base on a high silica low alumina clay is noticed. In Figure 7 the four curves for the various groups are given and the increasing slant is shown.

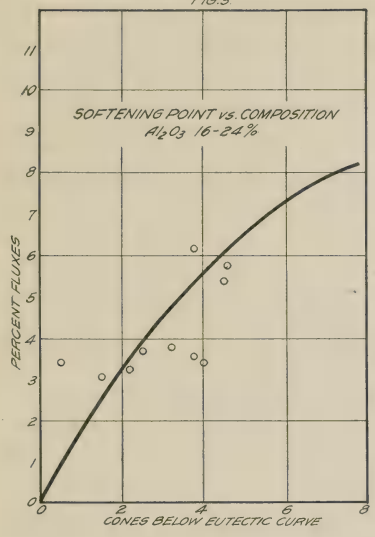
Discussion. Owing to the lack of clay samples containing from 8 to 16 percent alumina information on this range was not obtained, but the indications are that as the eutectic point is approached the fluxing effect of small amounts of bases would be less, as the clay would soften as a whole quite sharply at cone 26 instead of softening more slowly, due to the melting of the eutectic mixture and solution before the body as a whole would soften. It would seem that with 14 to 18 percent alumina as expressed in column 6, Table I, we probably have the maximum effect of small percents of fluxes.

With less than 8 percent alumina the effect of the fluxes, without doubt, decreases quite rapidly as the alumina decreases. The curve is not drawn in Figure 7 as the data at hand does not warrant it, but with the silica-clay mixtures plotted in Figure 1, the softening point in no case was over two cones below the eutectic line while the percent of flux was in some cases as high as 4.5 percent. From this we should judge that the curve for 0-8 percent alumina would be about the same as for 40 to 48 percent alumina.

Conclusions. It is of course recognized that these curves are not entirely correct, and that many special cases will be found where they do not apply, but they do undoubtedly apply to the samples here considered in showing the general tendency and the effect of the main constituents of a clay on the softening point. It also shows about what use can be made of the chemical analysis, as far as predicting the softening point is concerned. The following main points are brought out.

TRANS. AM. CER. SOC. VOL. XIX

FIG. 3.



MONTGOMERY & FULTON

FIG. 4.

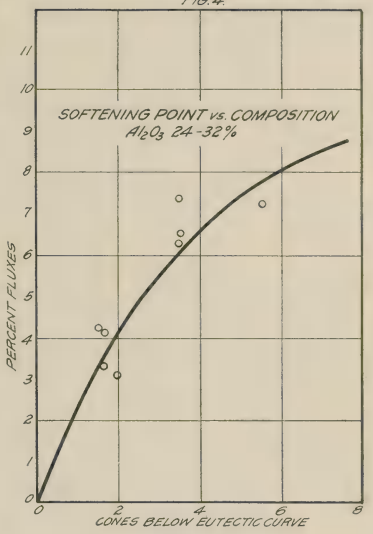


FIG. 5.

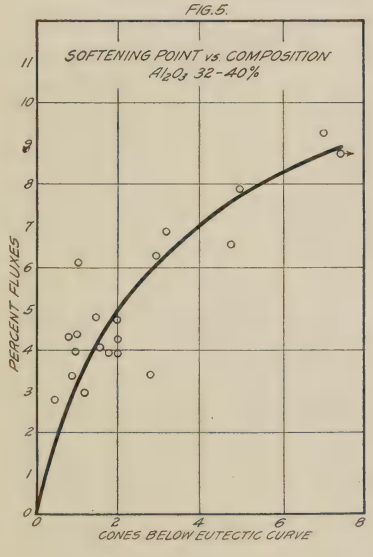
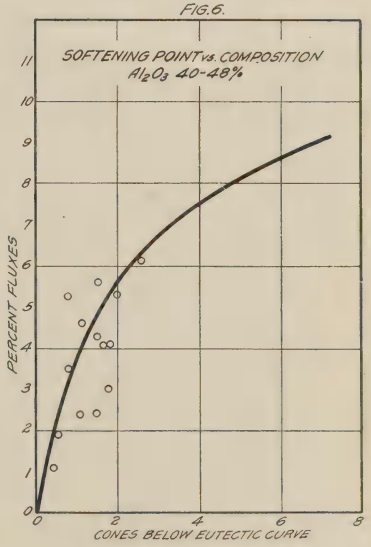


FIG. 6.

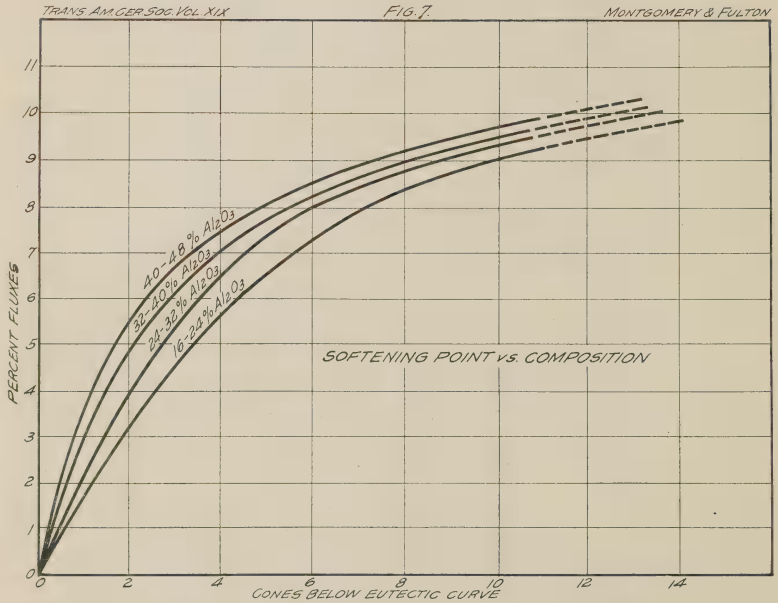


1. The silica-alumina eutectic curve limits the refractoriness of a clay.

2. The drop below this eutectic line in cones depends primarily upon the percent of flux present.

3. As the amount of flux increases, its activity increases rapidly.

4. About 14 to 18 percent alumina (based on alumina plus silica = 100) will give the maximum activity of the fluxes present.



5. With high silica beyond the eutectic point, the activity of the fluxes decreases rapidly.

DISCUSSION SUBMITTED AFTER READING PAPER

Mr. Staley: The work presented in this paper is along the same lines as that of Ritcher[1], Seger[2], Cramer[3], Rieke[4], Ludwig[5],

[1] Inaug. Diss. Reprint, 2d ed., *Tonindustrie Ztg.*, p. 1897.
[2] *Collected Writing*, p. 545.
[3] *Tonindustrie Ztg.*, *1895*, pp. 633 and 647.
[4] *Sprechsaal*, *43*, pp. 198-200, 314-317, 229-232.
[5] *Tonindustrie Ztg.*, *28*, p. 773.

Flach[6], and others. By plotting their results with reference to the silica-alumnia fusibility line, the authors have made evident the relation between composition of fire clays and their fusion temperature.

In using percents instead of empirical formulae for plotting their results, they are supported by the finding of Rieke and Flasch, that "equimolecular" amounts of the various fluxing oxides do not have the same effect on fusibility. It would be interesting, however, to know if their results would be more consistent if empirical formulae were used.

If a simple rule for determining the fusibility of fire clays based on ultimate chemical analysis can be devised, it will mean that the state of combination of the various elements present can be ignored. Of course we know that in constitution a clay is not a mixture of Al_2O_3, SiO_2 and fluxing oxides. On the other hand, a clay is composed of minerals in which the individual elements shown in this arbitrary arrangement into oxides are grouped in various combinations. The fusibility of a clay is supposed, according to physical chemical reasoning, to depend on the physical and chemical characteristics, number, and proportions of these various minerals. It may be that these factors can be ignored and that the fusibility of a clay is simply a matter of percentage composition; but if this is proven, it will call for some radical changes in our ideas of the physical chemistry of fusion phenomona.

Mr. Ries: As the authors state, practically all the clays considered by them were very fine-grained ones, and upon this it seems to me largely depends any uniformity of results which they may obtain. A second factor will be the uniformity of distribution of the several ingredients. If we are sure of these two, we can use a chemical analysis for interpretations regarding possible degree of refractoriness, but unless these data accompany an analysis or are known to us, the use of the chemical composition is in my opinion unsafe, and unwarranted for any ceramic purpose.

[6] *Sprechsaal*, 44, pp. 171-173, 187-189, 205-207, 219-221.

A STUDY OF THREE COMPONENT NORMATIVE SYSTEMS IN RAW LEAD GLAZES

BY WM. G. WHITFORD, CHICAGO, ILLINOIS.

The first notice of the use of norms in the calculation of glazes was made by Staley in the *Transactions of the American Ceramic Society, Vol. XIII,* p. 126, in which he states that, "This is an adaptation of the quantitative classification of the igneous rocks.[1] The basic idea of this classification is that the salts in solution in rock magmas may properly be considered to have the composition of those minerals which separate and crystallize when the magmas solidify. The 'Norm' of a rock magma is its standard mineral constitution, as calculated by this method."

Since this time, this method has been used in several investigations that have been presented to the Society. Purdy used this method of calculation in "A Study of Glaze Composition on the Bases of 'Norms'", *Trans. Amer. Cer. Soc., Vol. XIV,* p. 95. In the discussion of this paper, it was clearly brought out by Bleininger and Purdy, that care must be taken not to assume that the norms used are minerals actually formed in the glaze, Professor Bleininger being of the opinion that we did not have enough data at that time to justify the use of the normative system of calculation in glazes.

This method was used by Potts in an article entitled, "Notes on Mat Glazes," *Trans. Amer. Cer. Soc., Vol. XV,* p. 628. In a discussion of this paper, Bleininger called attention to the fact that Shumacker used this system in calculating glazes before the time of Seger. Staley made the following statement as to the use of the normative system of calculation. "In regard to the norm constitution of glazes, I stand sponsor for this in a way, being the first one to suggest it in our Transactions. I might say that, to my mind, it is a method of calculation pure

[1] *Quantitative Classification of Igneous Rocks* by Cross, Iddings, Pirsson and Washington, University of Chicago Press.

and simple. It is a means of obtaining an end. I do not believe anyone has ever claimed that these minerals do positively form. It is simply a method of calculation which amounts to variation of groups of oxides rather than variation of single oxides, as is the case in the ordinary empirical formulæ." This statement embodies the belief of the present author in regard to the use of norms in glaz work.

In Vol. XVIII, p. 424, *Trans. Amer. Cer. Soc.*, Watts presents an article entitled "A Study of Bristol Glazes Compounded on the Norm Basis." The use of norms has been used in part in several other investigations reported in the *Transactions*.

In planning the present investigation, care was taken to choose normative end members which were quite simple in composition and between which we had every reason to believe there would be no chemical reaction and no compounds formed. This gives us a large series of glazes in which the normative composition varies in regular manner and reduces to a minimum the necessity for making assumptions in regard to mineralogical composition in explaining variation in physical properties.

ANORTHITE SERIES

In this series the normative end members were:

K_2O, Al_2O_3, 6 SiO_2, Orthoclase, potash feldspar,

CaO, Al_2O_3, 2 SiO_2, Anorthite, made from 1 formula weight of whiting and 1 formula weight of North Carolina kaolin.

PbO, SiO_2, Lead metasilicate, made from 1 equivalent (1/3 formula weight) of white lead and 1 formula weight of flint.

On account of the difficulty of floating a glaze containing no clay, the line of compositions shown in Fig. 1 consisting of mixtures of orthoclase and lead metasilicate was not made up. Glaze Nos. 1, 10 and 55 were ground in large quantities, and the other members of the series were made from blends of these.

The compositions and empirical formulæ are given in Table I, the batch weights in Table II. The glazes were applied to white wall-tile biscuit.

The textures developed at cones 05, 02, 1 and 3, in oil-fired muffle laboratory kilns in burns varying from 12 to 16 hours, are shown in Figures 1, 2, 3 and 4. The glazes indicated as Bristol type in these figures are not necessarily good stoneware, glazes, but are more or less opaque and have a lustre corresponding to that of glazes ordinarily used for stoneware.

TABLE I — ANORTHITE SERIES — COMPOSITION OF GLAZES

NO.	NORMATIVE COMPOSITION			EMPIRICAL FORMULAE					OXYGEN RATIO
	ORTHO CLASE	ANOR-THITE	LEAD SILICATE	PbO	CaO	K_2O	Al_2O_3	SiO_2	
1	.9	.1	..	..	.1	.9	1.0	5.6	2.80
2	.8	.1	.1	.1	.1	.8	.9	5.1	2.75
3	.7	.1	.2	.2	.1	.7	.8	4.6	2.70
4	.6	.1	.3	.3	.1	.6	.7	4.1	2.65
5	.5	.1	.4	.4	.1	.5	.6	3.6	2.60
6	.4	.1	.5	.5	.1	.4	.5	3.1	2.50
7	.3	.1	.6	.6	.1	.3	.4	2.6	2.40
8	.2	.1	.7	.7	.1	.2	.3	2.1	2.2
9	.1	.1	.8	.8	.1	.1	.2	1.6	2.0
10	..	.1	.9	.9	.1	..	.1	1.1	1.7
12	.7	.2	.1	.1	.2	.7	.9	4.7	2.54
13	.6	.2	.2	.2	.2	.6	.8	4.2	2.47
14	.5	.2	.3	.3	.2	.5	.7	3.7	2.38
15	.4	.2	.4	.4	.2	.4	.6	3.2	2.28
16	.3	.2	.5	.5	.2	.3	.5	2.7	2.16
17	.2	.2	.6	.6	.2	.2	.4	2.2	2.00
18	.1	.2	.7	.7	.2	.1	.3	1.7	1.79
19	..	.2	.8	.8	.2	..	.2	1.2	1.50
21	.6	.3	.1	.1	.3	.6	.9	4.3	2.32
22	.5	.3	.2	.2	.3	.5	.8	3.8	2.23
23	.4	.3	.3	.3	.3	.4	.7	3.3	2.12
24	.3	.3	.4	.4	.3	.3	.6	2.8	2.00
25	.2	.3	.5	.5	.3	.2	.5	2.3	1.84
26	.1	.3	.6	.6	.3	.1	.4	1.8	1.63
27	..	.3	.7	.7	.3	..	.3	1.3	1.37
29	.5	.4	.1	.1	.4	.5	.9	3.9	2.10
30	.4	.4	.2	.2	.4	.4	.8	3.4	2.00
31	.3	.4	.3	.3	.4	.3	.7	2.9	1.87
32	.2	.4	.4	.4	.4	.2	.6	2.4	1.71
33	.1	.4	.5	.5	.4	.1	.5	1.9	1.52
34	..	.4	.6	.6	.4	..	.4	1.4	1.27
39	.1	.5	.4	.4	.5	.1	.6	2.0	1.43
40	..	.5	.5	.5	.5	..	.5	1.5	1.20
45	..	.6	.4	.4	.6	..	.6	1.6	1.14
55	..	1.0	..	..	1.0	..	1.0	2.0	1.00

TABLE II — ANORTHITE SERIES — COMPOSITION OF GLAZES — BATCH WEIGHTS

NO.	WHITE LEAD	WHITING	FELDSPAR	KAOLIN	FLINT	TOTAL
1	....	10.0	501.3	25.8	....	537.1
2	25.8	10.0	445.6	25.8	6.0	513.2
3	51.6	10.0	389.9	25.8	12.0	489.3
4	77.4	10.0	334.2	25.8	18.0	465.4
5	103.2	10.0	278.5	25.8	24.0	441.5
6	129.0	10.0	222.8	25.8	30.0	417.6
7	154.8	10.0	161.1	25.8	36.0	387.7
8	180.6	10.0	111.4	25.8	42.0	369.8
9	206.4	10.0	55.7	25.8	48.0	345.9
10	232.2	10.0	....	25.8	54.0	322.0
12	25.8	20.0	389.9	51.6	6.0	493.3
13	51.6	20.0	334.2	51.6	12.0	469.4
14	77.4	20.0	278.5	51.6	18.0	445.5
15	103.2	20.0	222.8	51.6	24.0	421.6
16	129.0	20.0	161.1	51.6	30.0	391.7
17	154.8	20.0	111.4	51.6	36.0	373.8
18	180.6	20.0	55.7	51.6	42.0	349.9
19	206.4	20.0	....	51.6	48.0	326.0
21	25.8	30.0	334.2	77.4	6.0	473.4
22	51.6	30.0	278.5	77.4	12.0	449.5
23	77.4	30.0	222.8	77.4	18.0	425.6
24	103.2	30.0	161.1	77.4	24.0	395.7
25	129.0	30.0	111.4	77.4	30.0	377.8
26	154.8	30.0	55.7	77.4	36.0	353.9
27	180.6	30.0	....	77.4	42.0	330.0
29	25.8	40.0	278.5	103.2	6.0	453.5
30	51.6	40.	222.8	103.2	12.0	429.6
31	77.4	40.	161.1	103.2	18.0	399.7
32	103.2	40.	111.4	103.2	24.0	381.8
33	129.0	40.	55.7	103.2	30.0	357.9
34	154.8	40.	....	103.2	36.0	334.0
39	103.2	50.	55.7	129.0	24.0	361.9
40	129.0	50.	....	129.0	30.0	338.0
45	103.2	60.	....	154.8	24.0	342.0
55	....	100.	....	258.0	....	358.0

There is a possibility that such glazes might be used in art pottery.

In each of the areas plotted, all of the glazes were not equally mature or of equally desirable texture and lustre. The plotting simply indicates that these glazes fell into one of the five classes indicated. In many cases it was found that a glaze would be mature enough at a low temperature to be considered a good mat or Bristol type, but as the temperature was raised

it would turn into a slightly immature bright glaze containing a considerable amount of pin-holes and bubbles.

Variation in Composition: Increase of lead silicate with corresponding decrease of feldspar makes the glazes more fluid, of higher gloss, more yellow and tends to turn Bristol type and semi-mat glazes into bright glazes. In this case the semi-mat glazes are in all probability immature bright glazes. In mat glazes it tends to produce a coarser grained texture, but in no case in this series did it turn a true mat into a bright glaze.

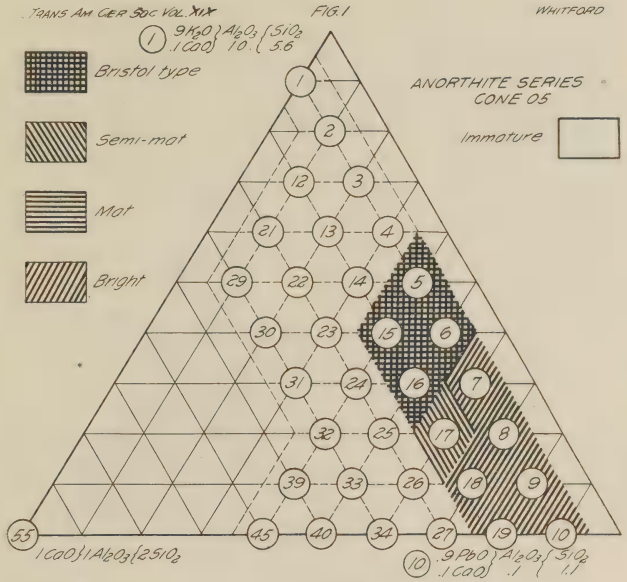
Increase of lead silicate and decrease of anorthite increase the fusibility of the glaze very markedly. It increases the tendency to yellow color and tends to change mat glazes into semi-mats, and semi-mats and Bristol type glazes into bright glazes.

It is noteworthy that the gradation in properties of the various glazes varied in regular order with composition, from end member to end member.

Variation of Temperature: Increase of temperature tends to increase the area of bright glazes centering around the lead silicate norm corner of the charts, the semi-mats and Bristol type being changed into bright glazes, the mats into semi-mats, and the area for mat glazes being shifted to a higher content of anorthite, among what were the immature glazes at a lower temperature.

The Mat Glaze Area: In this study it appears that at least .3 equivalent of anorthite norm was necessary for the production of a true mat at cone 02, and at least .4 equivalent of anorthite norm for a true mat at cone 3. This indicates that matness is a function, in part, of composition and in part of temperature. It must be remembered that increase of anorthite norm really means an increase of clay and whiting. The matness may be due simply to the increase of clay as has been claimed by some writers.

A line running from the lead silicate apex of the triangle to glaze No. 30 in the figures touches all the glazes having an oxygen ratio of 1 :2. Those above the line have an oxygen ratio higher than 1 :2, those below have an oxygen ratio lower than 1 :2. By reference to the chart it will be seen that all the true mats have an oxygen ratio of less than 1 :2, but there are also


TRANS AM CER SOC VOL XIX
FIG. 1
WHITFORD
Bristol type
Semi-mat
Mat
Bright
ANORTHITE SERIES
CONE 05
Immature
1 CaO } 1 Al2O3 { 2 SiO2
55
10 .9 PbO } Al2O3 { SiO2
.1 CaO } .1 { 1.1

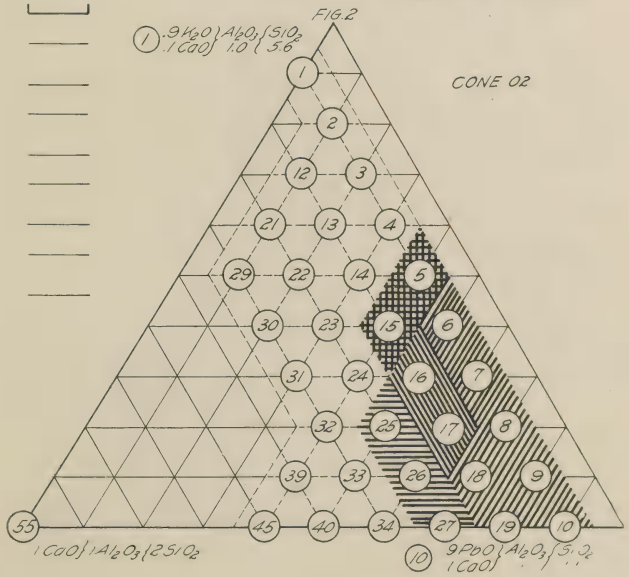
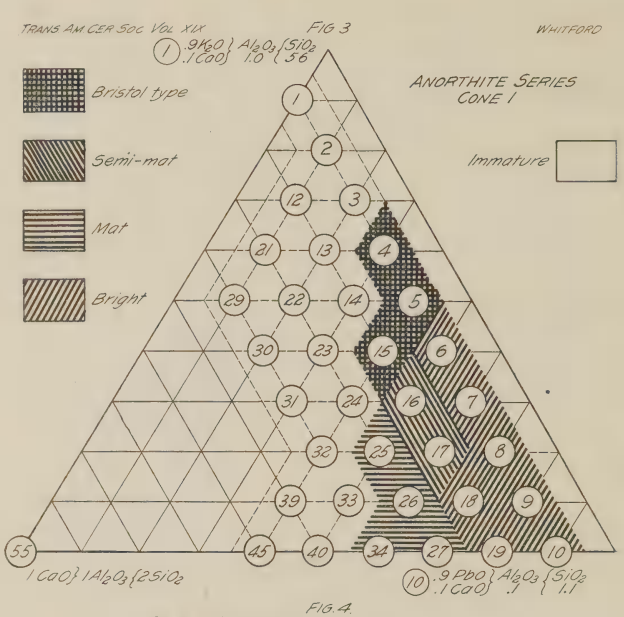


FIG. 2
1 .9 K2O } Al2O3 { SiO2
.1 CaO } 1.0 { 5.6
CONE 02
1 CaO } 1 Al2O3 { 2 SiO2
55
10 .9 PbO } Al2O3 { SiO2
.1 CaO } .1 { 1.1


TRANS AM CER SOC VOL XIX
FIG 3
WHITFORD
(1) .9 K2O } Al2O3 { SiO2
.1 CaO } 1.0 { 3.6
ANORTHITE SERIES
CONE 1
Bristol type
Semi-mat
Mat
Bright
Immature
1 CaO } 1 Al2O3 { 2.5 SiO2
(10) .9 PbO } Al2O3 { SiO2
.1 CaO } .1 { 1.1

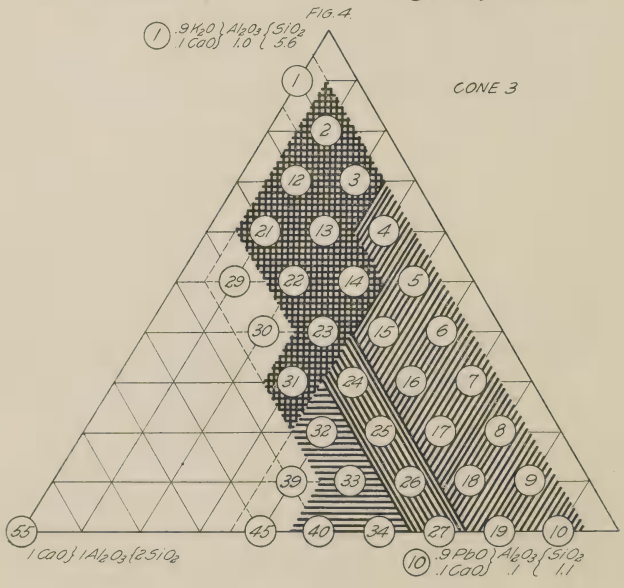


FIG. 4.
(1) .9 K2O } Al2O3 { SiO2
.1 CaO } 1.0 { 3.6
CONE 3
1 CaO } 1 Al2O3 { 2.5 SiO2
(10) .9 PbO } Al2O3 { SiO2
.1 CaO } .1 { 1.1

quite a number of bright glazes which have an oxygen ratio of less than 1:2. It thus seems that there is no definite relation between oxygen ratio and matness in this series. At each temperature the line dividing mat glazes from semi-mat and bright glazes is fixed by a certain minimum anorthite norm content.

WOLLASTONITE SERIES

In this series the norms chosen as end members were:

K_2O, Al_2O_3, 6 SiO_2, Orthoclase, potash feldspar

CaO, SiO_2,, Wollastonite, made from 1 formula weight of whiting and 1 formula weight of flint

PbO, SiO_2, lead metasilicate, made from 1 equivalent (1/3 formula weight) white lead and 1 formula weight of flint.

Owing to the difficulty of floating glazes containing no clay, 1/10 formula weight of anorthite (made from 1 formula weight of North Carolina kaolin and 1 formula weight of whiting) was incorporated in each of the glazes that were made up.

The normative compositions and empirical formulæ of this series are given in Table III, the batch weights in Table IV. The textures developed are shown in Figures 5, 6, 7 and 8.

Variation in Composition: Increase of lead silicate norm and decrease of feldspar give the same results as it did in the anorthite series. It makes the glazes more fluid, of higher gloss and more yellow.

Increase of lead silicate and decrease of wollastonite make the glazes more fluid, more yellow and tend to change the mat glazes to semi-mats, and the semi-mats and Bristol types to bright glazes.

Increase of wollastonite and decrease of feldspar seem to have little effect upon maturity. Glazes low in lead tend to produce semi-mats and mats.

Variation of Temperature: Increase of temperature increases the area of bright glazes, pushing the area of semi-mats and mats over towards the wollastonite corner of the series. Taken as a whole, the wollastonite series is a great deal more fusible than the anorthite series and produces a larger proportion of bright glazes.

TABLE III — WOLLASTONITE SERIES — COMPOSITION OF GLAZES

NO.	NORMATIVE COMPOSITION				EMPIRICAL FORMULAE					OXYGEN RATIO
	ORTHOCLASE	ANORTHITE	WOLLASTONITE	LEAD SILICATE	PbO	CaO	K_2O	Al_2O_3	SiO_2	
1	.9	.1	..	..	..	.1	.9	1.0	5.6	2.80
2	.8	.1	..	.1	.1	.1	.8	.9	5.1	2.75
3	.7	.1	..	.2	.2	.1	.7	.8	4.6	2.70
4	.6	.1	..	.3	.3	.1	.6	.7	4.1	2.65
5	.5	.1	..	.4	.4	.1	.5	.6	3.6	2.6
6	.4	.1	..	.5	.5	.1	.4	.5	3.1	2.5
7	.3	.1	..	.6	.6	.1	.3	.4	2 6	2.4
8	.2	.1	..	.7	.7	.1	.2	.3	2.1	2.2
9	.1	.1	..	.8	.8	.1	.1	.2	1.6	2.0
10	..	.1	..	.9	.9	.1	..	.1	1.1	1.7
12	.7	.1	.1	.1	.1	.2	.7	.8	4.6	2.70
13	.6	.1	.1	.2	.2	.2	.6	.7	4.1	2.64
14	.5	.1	.1	.3	.3	.2	.5	.6	3.6	2.57
15	.4	.1	.1	.4	.4	.2	.4	.5	3.1	2.48
16	.3	.1	.1	.5	.5	.2	.3	.4	2.6	2.36
17	.2	.1	.1	.6	.6	.2	.2	.3	2.1	2.21
18	.1	.1	.1	.7	.7	.2	.1	.2	1.6	2.00
19	..	.1	.1	.8	.8	.2	..	.1	1.1	1.69
21	.6	.1	.2	.1	.1	.3	.6	.7	4.1	2.64
22	.5	.1	.2	.2	.2	.3	.5	.6	3.6	2.57
23	.4	.1	.2	.3	.3	.3	.4	.5	3.1	2.48
24	.3	.1	.2	.4	.4	.3	.3	.4	2.6	2.36
15	.4	.1	.1	.4	.4	.2	.4	.5	3.2	2.48
25	.2	.1	.2	.5	.5	.3	.2	.3	2.1	2.21
26	.1	.1	.2	.6	.6	.3	.1	.2	1.6	2.00
27	..	.1	.2	.7	.7	.3	..	.1	1.1	1.69
29	.5	.1	.3	.1	.1	.4	.5	.6	3.6	2.57
30	.4	.1	.3	.2	.2	.4	.4	.5	3.1	2.48
31	.3	.1	.3	.3	.3	.4	.3	.4	2.6	2.36
32	.2	.1	.3	.4	.4	.4	.2	.3	2.1	2.21
33	.1	.1	.3	.5	.5	.4	.1	.2	1.6	2.00
34	..	.1	.3	.6	.6	.4	..	.1	1.1	1.69
37	.3	.1	.4	.2	.2	.5	.3	.4	2.6	2.36
38	.2	.1	.4	.3	.3	.5	.2	.3	2.1	2.21
39	.1	.1	.4	.4	.4	.5	.1	.2	1.6	2.00
40	..	.1	.4	.5	.5	.5	..	.1	1.1	1.69
43	.2	.1	.5	.2	.2	.6	.2	.3	2.1	2.21
44	.1	.1	.5	.3	.3	.6	.1	.2	2.1	2.21
45	..	.1	.5	.4	.4	.6	..	.1	1.1	1.69
48	.1	.1	.6	.2	.2	.7	.1	.2	1.6	2.00
49	..	.1	.6	.3	.3	.7	..	.1	1.1	1.69
52	..	.1	.7	.2	.2	.8	..	.1	1.1	1.69
55	..	.1	.9	..	..	1.0	..	.1	1.1	1.69

TABLE IV — WOLLASTONITE SERIES — COMPOSITION OF GLAZES — BATCH WEIGHTS

NO.	WHITE LEAD	WHITING	FELDSPAR	KAOLIN	FLINT	TOTAL
1	....	10.0	501.3	25.8	....	537.1
2	25.8	10.0	445.6	25.8	6.0	513.2
3	51.6	10.0	389.9	25.8	12.0	489.3
4	77.4	10.0	334.2	25.8	18.0	465.4
5	103.2	10.0	278.5	25.8	24.0	441.5
6	129.0	10.0	222.8	25.8	30.0	417.6
7	154.8	10.0	161.1	25.8	36.0	387.7
8	180.6	10.0	111.4	25.8	42.0	369.8
9	206.4	10.0	55.7	25.8	48.0	345.9
10	232.2	10.0	....	25.8	54.0	322.0
12	25.8	20.0	389.9	25.8	12.0	473.5
13	51.6	20.0	334.2	25.8	18.0	449.6
14	77.4	20.0	278.5	25.8	24.0	425.7
15	103.2	20.0	222.8	25.8	30.0	401.8
16	129.0	20.0	161.1	25.8	36.0	371.9
17	154.8	20.0	111.4	25.8	42.0	354.0
18	180.6	20.0	55.7	25.8	48.0	330 1
19	206.4	20.0	....	25.8	54.0	306.2
21	25.8	30.0	334.2	25.8	18.0	433.8
22	51.6	30.0	278.5	25.8	24.0	409.9
23	77.4	30.0	222.8	25.8	30.0	386.0
24	103.2	30.0	161.1	25.8	36.0	356.1
25	129.0	30.0	111.4	25.8	42.0	338 2
26	154.8	30.0	55.7	25.8	48.0	314.3
27	180.6	30.0	....	25.8	54.0	290.4
29	25.8	40.0	278.5	25.8	24.0	394.1
30	51.6	40.0	222.8	25.8	30.0	370.2
31	77.4	40.0	161.1	25.8	36.0	340.3
32	103.2	40.0	111.4	25.8	42.0	322.4
33	129.0	40.0	55.7	25.8	48.0	298.5
34	154.8	40.0	....	25.8	54.0	274.6
37	51.6	50.0	161.1	25.8	36.0	324.5
38	77.4	50.0	111.4	25.8	42.0	306.6
39	103.2	50.0	55.7	25.8	48.0	282.7
40	129.0	50.0	....	25.8	54.0	258.8
43	51.6	60.0	111.4	25.8	42.0	290.8
44	77.4	60.0	55.7	25.8	48.0	268.9
45	103.2	60.0	....	25.8	54.0	243.0
48	51.6	70.0	55.7	25.8	48.0	251.1
49	77.4	70.0	....	25.8	54.0	227.2
52	51.6	80.0	....	25.8	54.0	211.4
55	....	100.0	....	25.8	54.0	179.8

In this series there is an indication of a slight eutectic effect. The glazes having a medium amount of wollastonite norm and orthoclase are slightly more fusible than those high in either one of these ingredients and having the same lead silicate con-

tent. This is indicated, in the Figures by the fact that in the region of medium amounts of wollastonite and orthoclase, the area of bright and Bristol type glazes projects farther away from the lead silicate corner than it does in adjoining regions.

Mat Glaze Area. The lines of equal oxygen ratio in this series run horizontally across the chart, the line of oxygen ratio 1:2 runs from No. 9 to No. 48. The glazes on the base line have an oxygen ratio of 1:1.69. By reference to the charts it will be seen that we had from three to five glazes in each burn that came bright at an oxygen ratio of 1.69 and one or two glazes that came mat or semi-mat with an oxygen ratio of 1:2. One glaze, (No. 43) came semi-mat at cone 3, altho it had an oxygen ratio of 1:2.21. In this series then, while all mat and semi-mat glazes had a comparatively low oxygen ratio, a considerable number of glazes came bright with an oxyen ratio of less than 1.2. Matness seems to be a function of temperature and composition. A minimum content of wollastonite being necessary for each temperature. Thus the line separating the semi-mat glazes from the bright glazes is fixed on the charts by the position of this amount of wollastonite and not by any oxygen ratio line. In this series we found two glazes that were good mats through a range of several cones, which had an Al_2O_3 content of only .1 equivalent. This is rather unusual and contrary to the generally accepted views regarding the amount of alumina necessary to produce mats of the lime-alumina type. Three-tenths equivalent of alumina is generally considered necessary for the production of matness. See Purdy, Mat Glazes *Vol XIV, Trans. Amer Cer. Soc.*

The mat glazes obtained in this series were of the fine textured silky type more pleasing than those of the other two series.

ZINC SILICATE SERIES

This series was made up in the same way as the wollastonite series, except that zinc silicate norm was used in place of wollastonite norm.

In this series the normative end members were:

K_2O, Al_2O_3, 6 SiO_2, Orthoclase, potash feldspar,

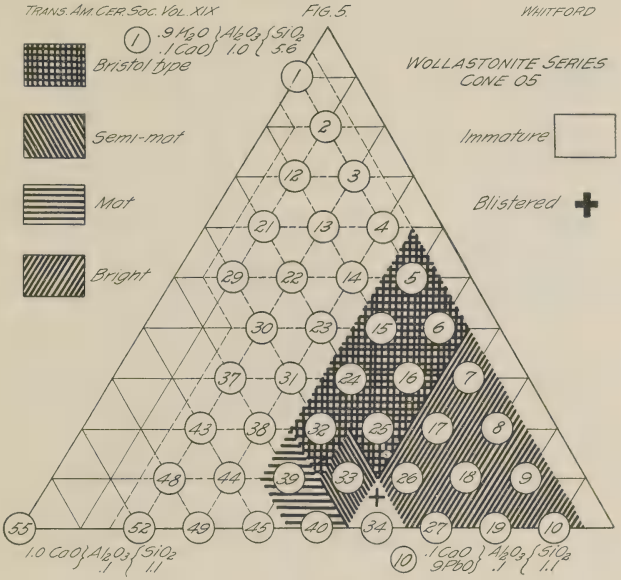
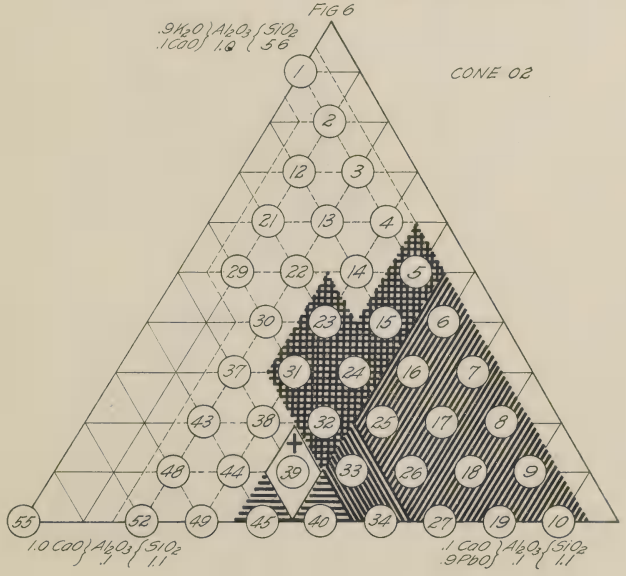
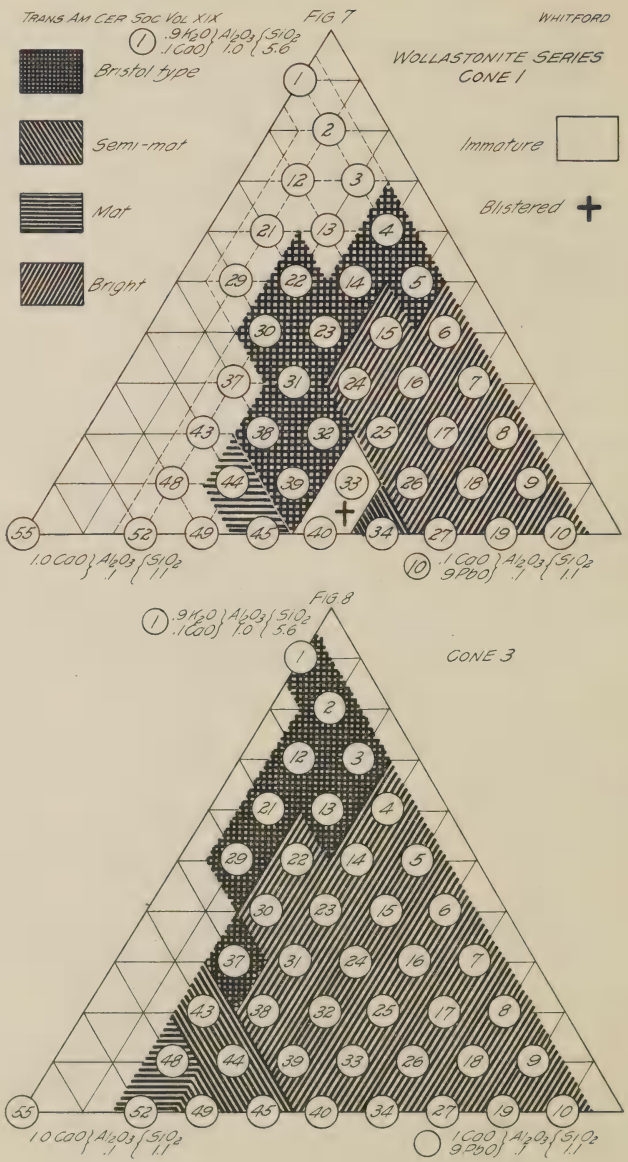

TRANS. AM. CER. SOC. VOL. XIX
FIG. 5.
WHITFORD
WOLLASTONITE SERIES
CONE 05
Bristol type
Semi-mat
Mat
Bright
Immature
Blistered

FIG 6


CONE 02


TRANS AM CER SOC VOL XIX
FIG 7
WHITFORD
WOLLASTONITE SERIES
CONE 1
Bristol type
Semi-mat
Mat
Bright
Immature
Blistered
FIG 8
CONE 3

ZnO, SiO_2, zinc metasilicate, made from 1 formula weight zinc oxide and 1 formula weight of flint.

PbO, SiO_2, lead metasilicate, made from 1 equivalent (1/3 formula weight) white lead and 1 formula weight of flint.

Owing to the difficulty of floating glazes containing no clay 1/10 formula weight of anorthite was incorporated in each of the glazes, as in the wollastonite series.

The compositions and empirical formulæ are given in Table V, the batch weights in Table VI. The textures developed in this series are shown in Figures 9, 10, 11 and 12.

Variation of Composition: Increase of lead silicate norm and decrease of feldspar make the glazes more fusible, more yellow and of higher gloss. It turns Bristol type glazes into bright and semi-mats, semi-mats to mats, and mats to crystalline.

Increase of lead silicate norm and decrease of zinc silicate norm make the glazes more fusible, turns Bristol type and mats to bright and in two cases turns mats to crystalline and crystalline to bright glazes.

Increase of zinc silicate norm and decrease of feldspar turns Bristol type to bright, bright to semi-mat, mat or crystalline, and crystalline to bright glazes.

Increase of feldspar turns Bristol type to bright, bright to semi-mat, mat or crystalline, and in case of high zinc oxide, mats and semi-mats to opaque white enamels of the Bristol type, which are very badly crawled.

Variation of Temperature: Increase of temperature increases the area of bright glazes pushing areas of mats and semi-mats over toward the zinc silicate corner of the chart. Glazes No. 40 was persistently crystalline from cone 02 to cone 3. The crystallization occurred only in spots and around the edges. Possibly the crystal patches would have been greater in extent, and the crystalline area on the charts would have been larger, if the cooling treatment of the kilns had been more prolonged.

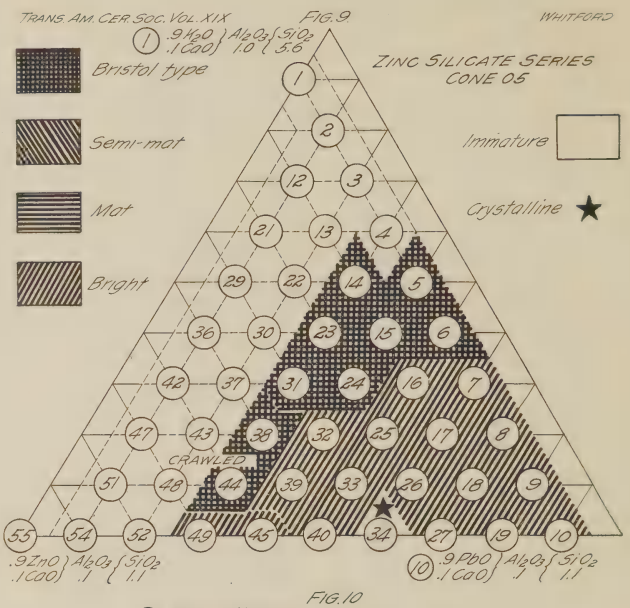
Mat Glaze Area: In this series also, the lines of equal oxygen ratio run horizontally across the chart. The oxygen ratio line of 1:2 runs from glaze No. 9 to No. 51. The mat and crystalline glazes come on or below this line, but we also found quite a number of good bright glazes under this line. The seem-

TABLE V — ZINC SILICATE SERIES — Concluded

NO.	NORMATIVE COMPOSITION				EMPIRICAL FORMULAE						OXYGEN RATIO
	ORTHOCLASE	ANORTHITE	ZINC SILICATE	LEAD SILICATE	ZnO	PbO	CaO	K_2O	Al_2O_3	SiO_2	
1	.9	.1	..	..	..	..	.1	.9	1.0	5.6	2.8
2	.8	.1	..	.1	..	.1	.1	.8	.9	5.1	2.75
3	.7	.1	..	.2	..	.2	.1	.7	.8	4.6	2.70
4	.6	.1	..	.3	..	.3	.1	.6	.7	4.1	2.65
5	.5	.1	..	.4	..	.4	.1	.5	.6	3.6	2.6
6	.4	.1	..	.5	..	.5	.1	.4	.5	3.1	2.5
7	.3	.1	..	.6	..	.6	.1	.3	.4	2.6	2.4
8	.2	.1	..	.7	..	.7	.1	.2	.3	2.1	2.2
9	.1	.1	..	.8	..	.8	.1	.1	.2	1.6	2.0
10	..	.1	..	.9	..	.9	.1	..	.1	1.1	1.7
12	.7	.1	.1	.1	.1	.1	.1	.7	.8	4.6	.270
13	.6	.1	.1	.2	.1	.2	.1	.6	.7	4.1	2.65
14	.5	.1	.1	.3	.1	.3	.1	.5	.6	3.6	2.6
15	.4	.1	.1	.4	.1	.4	.1	.4	.5	3.1	2.5
16	.3	.1	.1	.5	.1	.5	.1	.3	.4	2.6	2.4
17	.2	.1	.1	.6	.1	.6	.1	.2	.3	2.1	2.2
18	.1	.1	.1	.7	.1	.7	.1	.1	.2	1.6	2.0
19	..	.1	.1	.8	.1	.8	.1	..	.1	1.1	1.7
21	.6	.1	.2	.1	.2	.1	.1	.6	.7	4.1	2.65
22	.5	.1	.2	.2	.2	.2	.1	.5	.6	3.6	2.6
23	.4	.1	.2	.3	.2	.3	.1	.4	.5	3.1	2.5
24	.3	.1	.2	.4	.2	.4	.1	.3	.4	2.6	2.4
25	.2	.1	.2	.5	.2	.5	.1	.2	.3	2.1	2.2
26	.1	.1	.2	.6	.2	.6	.1	.1	.2	1.6	2.0
27	..	.1	.2	.7	.2	.7	.1	..	.1	1.1	1.7
29	.5	.1	.3	.1	.3	.1	.1	.5	.6	3.6	2.6
30	.4	.1	.3	.2	.3	.2	.1	.4	.5	3.1	2.5
31	.3	.1	.3	.3	.3	.3	.1	.3	.4	2.6	2.4
32	.2	.1	.3	.4	.3	.4	.1	.2	.3	2.1	2.2
33	.1	.1	.3	.5	.3	.5	.1	.1	.2	1.6	2.0
34	..	.1	.3	.6	.3	.6	.1	..	.1	1.1	1.7
36	.4	.1	.4	.1	.4	.1	.1	.4	.5	3.1	2.5
37	.3	.1	.4	.2	.4	.2	.1	.3	.4	2.6	2.4
38	.2	.1	.4	.3	.4	.3	.1	.2	.3	2.1	2.2
39	.1	.1	.4	.4	.4	.4	.1	.1	.2	1.6	2.0
40	..	.1	.4	.5	.4	.5	.1	..	.1	1.1	1.7
42	.3	.1	.5	.1	.5	.1	.1	.3	.4	2.6	2.4
43	.2	.1	.5	.2	.5	.2	.1	.2	.3	2.1	2.2
44	.1	.1	.5	.3	.5	.3	.1	.1	.2	1.6	2.0
45	..	.1	.5	.4	.5	.4	.1	..	.1	1.1	1.7
47	.2	.1	.6	.1	.6	.1	.1	.2	.3	2.1	2.2
48	.1	.1	.6	.2	.6	.2	.1	.1	.2	1.6	2.0
49	..	.1	.6	.3	.6	.3	.1	..	.1	1.1	1.7
51	.1	.1	.7	.1	.7	.1	.1	.1	.2	1.6	2.0
52	..	.1	.7	.2	.7	.2	.1	..	.1	1.1	1.7
54	..	.1	.8	.1	.8	.1	.1	..	.1	1.1	1.7
55	..	.1	.9	..	.9	..	.1	..	.1	1.1	1.7

TABLE VI — ZINC SILICATE SERIES — COMPOSITION OF GLAZES — BATCH WEIGHTS

NO.	ZINC OXIDE	WHITE LEAD	WHITING	FELDSPAR	KAOLIN	FLINT	TOTAL
1	....	.....	10.0	501.3	25.8	....	537.1
2	....	25.8	10.0	445.6	25.8	6.0	513.2
3	....	51.6	10.0	389.9	25.8	12.0	489.3
4	....	77.4	10.0	334.2	25.8	18.0	465.4
5	....	103.2	10.0	278.5	25.8	24.0	441.5
6	....	129.0	10.0	222.8	25.8	30.0	417.6
7	....	154.8	10.0	161.1	25.8	36.0	387.7
8	....	180.6	10.0	111.4	25.8	42.0	369.8
9	....	206.4	10.0	55.7	25.8	48.0	345.9
10	....	232.2	10.0	.....	25.8	54.0	322.0
12	8.1	25.8	10.0	389.9	25.8	12.0	471.6
13	8.1	51.6	10.0	334.2	25.8	18.0	447.7
14	8.1	77.4	10.0	278.5	25.8	24.0	423.8
15	8.1	103.2	10.0	222.8	25.8	30.0	399.9
16	8.1	129.0	10.0	161.1	25.8	36.0	370.0
17	8.1	154.8	10.0	111.4	25.8	42.0	352.1
18	8.1	180.6	10.0	55.7	25.8	48.0	328.2
19	8.1	206.4	10.0	.....	25.8	54.0	304.3
21	16.2	25.8	10.0	334.2	25.8	18.0	430.0
22	16.2	51.6	10.0	278.5	25.8	24.0	406.1
23	16.2	77.4	10.0	222.8	25.8	30.0	382.2
24	16.2	103.2	10.0	161.1	25.8	36.0	352.3
25	16.2	129.0	10.0	111.4	25.8	42.0	334.4
26	16.2	154.8	10.0	55.7	25.8	48.0	310.5
27	16.2	180.6	10.0	.....	25.8	54.0	286.6
29	24.3	25.8	10.0	278.5	25.8	24.0	388.4
30	24.3	51.6	10.0	222.8	25.8	30.0	364.5
31	24.3	77.4	10.0	161.1	25.8	36.0	234.6
32	24.3	103.2	10.0	111.4	25.8	42.0	316.7
33	24.3	129.0	10.0	55.7	25.8	48.0	292.8
34	24.3	154.8	10.0	.....	25.8	54.0	268.9
36	32.4	25.8	10.0	222.8	25.8	30.0	346.8
37	32.4	51.6	10.0	161.1	25.8	36.0	316.9
38	32.4	77.4	10.0	111.4	25.8	42.0	299.0
39	32.4	103.2	10.0	55.7	25.8	48.0	275.1
40	32.4	129.0	10.0	.....	25.8	54.0	251.2
42	40.5	25.8	10.0	161.1	25.8	36.0	299.2
43	40.5	51.6	10.0	111.4	25.8	42.0	281.3
44	40.5	77.4	10.0	55.7	25.8	48.0	257.4
45	40.5	103.2	10.0	.....	25.8	54.0	333.5
47	48.6	25.8	10.0	111.4	25.8	42.0	263.6
48	48.6	51.6	10.0	55.7	25.8	48.0	239.7
49	48.6	77.4	10.0	.....	25.8	54.0	215.8
51	56.7	25.8	10.0	55.7	25.8	48.0	222.0
52	56.7	51.6	10.0	.....	25.8	54.0	198.1
54	64.8	25.8	10.0	.....	25.8	54.0	180.4
55	72.9	.....	10.0	.....	25.8	54.0	162.7


TRANS. AM. CER. SOC. VOL. XIX
FIG. 9
WHITFORD
ZINC SILICATE SERIES
CONE 05
Bristol type
Semi-mat
Mat
Bright
Immature
Crystalline
CRAWLED
FIG. 10
CONE 02
Crawled
Crawled

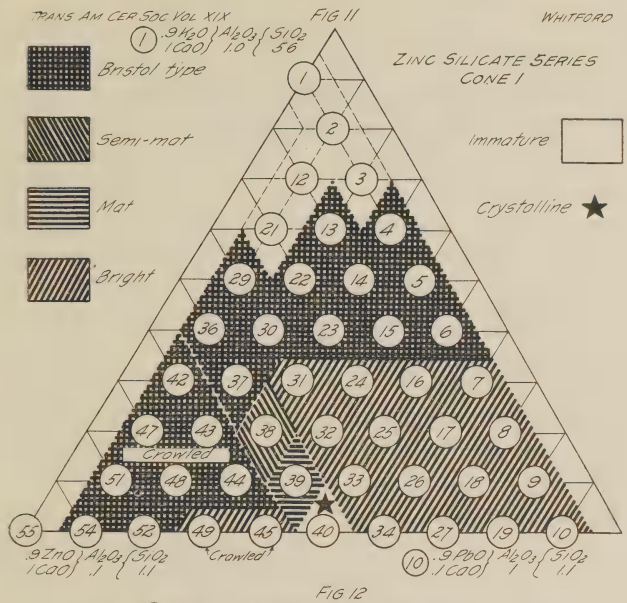
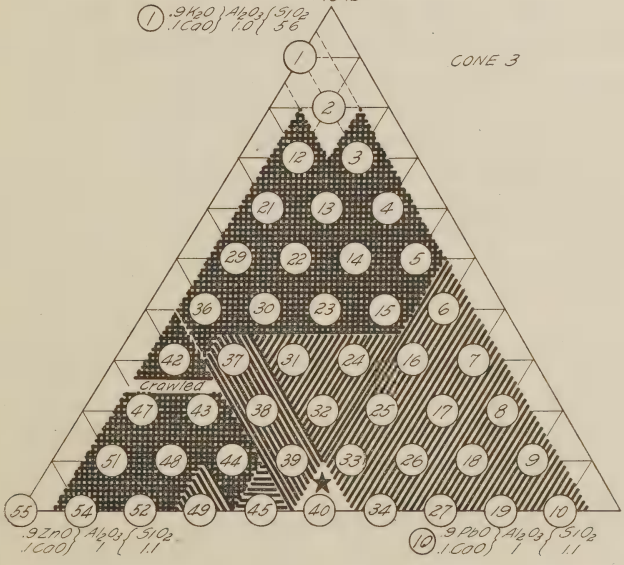

TRANS AM CER SOC VOL XIX
FIG 11
WHITFORD
ZINC SILICATE SERIES
CONE 1
Bristol type
Semi-mat
Mat
Bright
immature
Crystalline
Crowded
Crowded
Crowded

FIG 12


CONE 3
Crowded

ingly erratic variation in texture of the glazes in the area in which mats and crystalline glazes are found is explained by the fact that these mats are truly crystalline and therefore quite dependent on a certain fluidity and heat treatment for their production. Thus, glazes No. 45 and No. 49 were immature bright glazes at cones 05 and 02, but at higher temperatures they became fluid enough to permit the growth of crystals and became semi-mat and mat. In other glazes, the crystals producing mat and crystalline effects at low temperatures were dissolved in the glazes, when these were fired at higher temperatures, and failed to reappear during the sudden cooling of our small kiln.

GENERAL CONCLUSIONS

I. When the normative end members are properly chosen, the normative system of glaze calculation and blending gives series of glazes whose physical properties vary in regular and easily explicable manner.

II. Glazes made from blends of anorthite norm ($CaO\ Al_2O_3\ 2SiO_2$) with lead metasilicate norm ($PbO\ SiO_2$) and orthoclase gave more refractory glazes than those in the other two series and a large proportion of mat and semi-mat glazes. Matness was a function of temperature and composition, a certain minimum content of anorthite norm being essential at each heat treatment. The line dividing dull finish from bright glazes was fixed by this minimum anorthite content and bore no relation to oxygen ratios.

III. Glazes made from blends of wollastonite norm ($CaO\ SiO_2$) with lead metasilicate norm and orthoclase, were mostly bright. The few mats developed were of silky texture and had quite a low alumina contents. The line dividing dull finish from bright glazes was fixed at each temperature by a certain minimum wollastonite norm content.

IV. Glazes made from blends of zinc metasilicate norm ($ZnO\ SiO_2$) with lead metasilicate norm and orthoclase were mostly bright glazes and stoneware enamels. A few mats and crystalline glazes were produced. The mats in this series seem to be truly crystalline.

Ceramic Laboratories,
Engineering Experiment Station,
Iowa State College.

GLASS TANK-FURNACE OPERATION

BY R. L. FRINK, LANCASTER, OHIO.

In the past two or three years there has been more or less trouble experienced by tank-furnace operators in obtaining a glass satisfactory as to quality and color. The factory managers and glassmakers have attributed this trouble to everything from sand to manganese in raw materials, and from gas to weather conditions in furnace operation, and while raw materials, fuel and weather no doubt have, to a minor degree, been responsible for many annoyances, yet in some cases at least furnace construction and operation have been largely responsible for poor glass.

Many glassmakers are of the opinion that a glass can only be made of certain raw materials obtained from specific localities or manufacturers, and if their finished product is not of a character desired, then the raw materials are at fault. Because of a slight change in color, or because of some conditions of melting or character of glass, he deduces that more or less of certain material is required, that his sand is poor, or his chemicals are impure, and makes changes in batch accordingly. In due course of time, if the changes made have not corrected the fault, he makes another change, and perhaps the trouble ceases or is augmented, but anyhow after a time he gets conditions back to normal, convinced that some one of his remedies has effected the cure.

Now some old timers say: "Glass can be made from anything that will combine with sand if enough fire can get to it" — which is, I believe, a statement of fact, and which in a practical sense seems to be substantiated by reviewing some thousand or more batch formulas I have knowledge of. However, it is true and essential, that to make a glass for a specific purpose there is but one correct formula that is best for that specific purpose, and it is only best when made under correct

melting conditions relative to that particular formula or chemical composition.

An attempt to enumerate even the common defects in glass due to unbalanced chemical relations in the glass composition, or its relation to the melting conditions, would make a large volume. I will, therefore, call attention only to the most prominent conditions which affect color and quality of glass.

Let us consider a case wherein the principal conditions are known, the batch used consisting of:

	pounds
Sand	1,000
Burned lime	110
Soda ash	360
Nitre	20
Manganese	5·5
Arsenic	2

A glass of good quality and color was obtained during the fire of 1914, but in 1915 seedy glass of very low and erratic color was persistently present.

In 1914 approximately 7¾ pounds of glass per square foot per hour was melted with a natural gas consumption of 120 M. cu. ft. in 24 hours, while in 1915 there was melted 9¼ pounds with a gas consumption of 140 M. cu. ft. for 24 hours, or an increase of over 23 percent, but it was very difficult, or impossible, to obtain a fire which would melt this required amount without causing seeds and loss of color. There had been a gradual increase of manganese to 13 pounds per 1,000 pounds of sand with no benefit, in fact, the glass was a dirty green, and less saleable than that made with 6 pounds of manganese.

The fire was smoky, and the combustion was poor. The stack damper was raised, as was also the air valve, with but little benefit. Measurements of the draft pressure throughout the system gave: stack .88 inches; in flue between stack damper and air valve .62 inches; in checker chamber, under checker .57 inches; in chamber over checker .02 inches; in furnace .012 + inches. It was obvious, therefore, that there was not sufficient draft to relieve the furnace of burnt gases, and a con-

sequent back pressure on the incoming gases was obtained which, to a degree, lessened the amount of air entering the furnace, and consequently retarded combustion. The furnace temperature was below normal, and the surface of the glass was covered with a heavy scum, and a fierce "sting-out" was always present at the gathering holes, making it difficult to keep the men at work.

According to the statements of those in charge, they had in 1914 made a fair quality of glass, and during the fire of 1913 had still better glass, but that each year and month since the fire of 1913 the furnace had been more difficult to operate and obtain satisfactory color and quality. The trouble had been attributed to poor materials, and particularly to the quality of manganese, and also to batch mixing. Analysis of their materials showed all to be normal, but these analyses they would not accept, the argument being: "Here is the same tank, of the same dimensions, same kind of fuel, same men operating it who have made good glass for 20 years, and the only things that can change is the materials; your chemical "bunk" is expensive chatter, and there is something you don't find that is causing this." Careful investigation and questioning, however, revealed the following:

In 1913 the furnace was practically re-built by a prominent furnace builder, and designed for a capacity of 12 tons of glass per day, but toward the close of the 1914 fire there was produced nearly 14 tons with some trouble from poor color and seeds attending this production, although not serious. At the close of the 1914 fire, or in the summer of 1915, cold repairs were made, at which time the checkers were re-set and provisions made for one more shop using semi-automatic machines.

Inasmuch as it was anticipated that about 10 percent more melting capacity would be required, the management figured that more checker was necessary. To obtain this the checkers were set, using common fire brick for the lateral runs and the old 3 by 6 by 14 checker brick for the cross runs, from which all of the former checker was made. This gave about a 40 percent air opening, but this checker construction obviously

increased the friction very materially. Further, it was learned that the flue on one side had been forced in by the pressure of the loose earth surrounding it, so that its area was reduced by about 4 inches for a distance of nearly 14 ft., which caused additional friction.

The sum of this increased friction resulted in decreasing the melting capacity instead of increasing it. This was proven by the fact that on making repairs this last year, the flue was repaired, checkers re-set as to give a 60 percent air area in the checkers, and 10 ft. added to the height of the stack with the result that this furnace is now melting 9¼ to 9½ pounds per square foot and making excellent glass free from seeds and having an exceptionally constant and good color. The draft measurements now show: stack .9 inches; flue inside air valve .41 inches; under checkers .31 inches; over checker .16 inches; in furnace .00 or but a slightly + pressure. The sting-out is now not more than 2 inches long, and white.

This same condition may be found existing to a more or less degree in probably 25 percent of the plants throughout the country, particularly in the smaller plants.

Another condition is prevalent and worth mentioning here, *viz.:* Furnace men when getting into trouble with scum will drop their damper and air valve and "cut off the scum" as they believe. The result is that they lower the furnace temperature by producing incomplete combustion, and the high reducing atmosphere does tend to remove the scum, but they do much more. The glass at the melting end cools while the temperature of the glass at the surface in the working end increases; therefore that which flows from the melting- to the working end during this period carries less heat to the working end, and the men commence to complain because the glass is too stiff, so to increase the heat at the working end they lower the damper still further, until the sting-out existing there is so severe as to prevent good work being done, and the men increase their complaint.

The furnace man is now at his wits end, but his woe is increased by loss of color some three to six hours after his scum-removing and working-end-heating effort has been put into effect, and then come seeds with an additional following of cords and

stones. He dare not clean up his fire by raising his stack damper and air valve, for he reasons that by such procedure he will take the fire from the working end and "freeze" the glass, in consequence of which his workmen will quit. Therefore he and everybody suffers until Saturday, and from quitting time Saturday until Monday he opens up his dampers, cleans up his fire, and, in a measure, recuperates from the evil he has caused, but about Monday night, or Tuesday, scum begins to appear — so he repeats.

What he should have done would be to determine if his glass was balanced chemically, and if so, to raise both stack and air dampers, perhaps adding more gas, and thereby increase his fire and temperature to force combination of the batch constituents. Unless the working end is much greater in size than the melting end, he will have no cause for closing the stack damper to keep the glass hot enough for the workmen, or to keep away scum and maintain a glass of good color, free from seeds, cords and stones.

This, I presume, many will dispute; however, I know of several instances where this procedure has been followed with excellent results, but obviously this could not have effected a remedy in the first instance mentioned because of the choked flue and checker.

Further, just as soon as one attempts to keep the working end hot by forcing gases of combustion down there from the melting end, by producing insufficient draft, or introducing an excessive amount of gases into the furnace, he loses control of the color, of quality, as also the melting, for obviously to do so he must create a pressure in the melting end and thereby smother or retard combustion, and superimpose all the glass with a reducing atmosphere, which lowers the color by reducing the manganese, and the result is a green glass.

Another condition is found which, with sufficient air and draft, will cause these difficulties, *viz.*: if, when oil or natural gas is used, the entering fuel is directed in such a manner as to come in contact with the batch, glass, or port blocks before it has obtained sufficient air to support combustion, carbon will be de-

posited and absorbed in the melting mass with a consequent destruction of color, and the production of cords and seedy glass.

Burners should always be so placed as to obtain the best possible mixture of air in the shortest period of time and travel; also the size of burner should be so regulated that the pressure of the gas or oil will project a stream no greater in size, volume and velocity but what the incoming air can become so admixed that combustion begins immediately upon their entering the furnace.

The efficiency of a furnace largely depends upon the temperature of the checkers, and the manner in which such temperature is maintained. If the first instance prevails, considerable flame is seen entering top of checker chamber, but the checker temperature may not be above 1200° to 1700° F., and wholly insufficient to obtain a good fire and efficient operation, for because of a low temperature of furnace gases and retarded combustion, the checkers and flue to the stack may be as high as 1400° F., but if proper burner, pressure, air and damper regulation is effected, the top checker may be 2200° F., the bottom 1500° and the flue 900°, with stack at 700° to 800°, according to distance.

I have here presented a few of the principal confusing conditions which are most prevalent, and in language which I trust can be readily understood by the glassmaker and furnace operator, hoping it will interest them sufficiently that they will join us in discussing these subjects, and thereby assist in advancing an art about which we know so little of the fundamental principles, and of which definite knowledge is required that we may efficiently govern, control and predetermine our product.

DISCUSSION

Mr. Creighton: I should like to ask Mr. Frink, if it is a pertinent question, whether the trouble was due to an absorption of these uncombined gases or due to reducing effect in the glass itself?

Mr. Frink: I expected that question, and it is quite a long subject. That is one thing that I don't know that we can absolutely prove, one way or the other. I am of the opinion, how-

ever, that it is an absorption of the gases which causes the greater trouble. When we speak of reducing gases, we will assume that we refer then to CO_2, or perhaps a gas which contains in the neighborhood of 10 percent CO_2 might be called a reducing gas — that does not seem to make so very much difference in tank operation; but when we do get a gas which has free CO or has unconsumed gas, then we begin to get cords and loss of color absolutely; in other words, when that gas has impinged upon the batch pile before it has had time to either burn to CO or CO_2, then we have a complete loss of color.

Mr. Orton: Mr. Frink's talk has been interesting to me from the fact that during the year past, I was asked to come down to a glass works one Sunday and see whether I could advise them what was the cause of their trouble. This description fits the case most marvelously close. One of their furnaces had gone out of commission, and they tried to put more glass through the other and had increased its output 15 or 20 percent; I do not think they had made any construction details different in order to accomplish that, they simply tried to run the thing harder, their normal content of manganese being represented by the figure 17, whatever that may have been, points or pounds or whatever it is, I don't know. They found that their color was getting green, and they began increasing manganese and finally got up to 23 points without producing the proper return of the normal color. All at once the color came with a vengeance and went way beyond the proper amount and gave them the characteristic purple tint of manganese in such quantity that they had to scrap a good many tons of glass, and then they began coming back again in the same way that they had gone up, point by point, and finally got down to the point represented by 14, and then from the excess of manganese which they had charged into their tank in the preceding experiment, they returned once more to the green tint. So it was see-sawing backwards and forwards and trying to find the location between those points where their color would be normal. I saw the manager not long before this meeting, in fact tried to bring him here in order that he might hear your

paper on this point, but he was not able to come. He told me that, to a large extent, they had overcome the difficulty, but they did not know how they had overcome it, they had simply lived through the trouble, and in discussing with him his conditions at that time, I found out that they were pushing the furnace much harder, passing more fuel through it in a given time, and that, I told him, was a much more likely cause of the conditions that they were having than any actual change of the manganese itself. I believe if they had been able to melt the original batch of manganese in increased quantity, they would not have had any change in the color.

Mr. Hope: Mr. Frink has spoken of the increased gas pressure; I want to ask what effect, if any, that has on the time of fining the glass?

Mr. Frink: I don't know that I can give any facts in regard to that. We have noted, in the past two or three years, perhaps, two or three instances of where we thought — it was merely a thought — that when we had a sufficient draft in the furnace proper, that is, had a negative pressure in the furnace, our fining action was more rapid; that is, there seems to be three, as I recall, particular instances where we had seedy glass with a large, open seed, which we usually say is a fining seed; and when we increased our draft pressure in that particular furnace, that seed was eliminated, but whether it was because of a lack of pressure to hold it in or not, is problematical; I cannot say positively that there was really any definite proof one way or the other.

AMERICAN CLAYS FOR FLOATING ENAMELS

BY J. B. SHAW.

Like most other ceramic industries, the enameled iron industry was transported from Europe to America. The Germans, Austrians and Swedes have perfected this industry to a higher degree than in any other country, and what there is in this country is very largely that which has been brought here by men from these countries. It can probably be truly said that the enameled iron industry is more nearly in the primitive state than any other ceramic industry in the United States. Especially is this true of the "sheet iron" enameling industry. A very large proportion of the enamelers in this country are Germans, Austrians and Swedes. They occupy their positions, not because of superior ability but because of formulae which they have, and with which they are able to produce results. The natural consequence of this is that raw materials for making enamels have in the past been largely imported from these countries. One material especially which has been almost universally imported is German Valender clay which was used for floating the enamel frit and producing proper consistency for dipping. This was the state of affairs when the war started, and enamelers over the country were thrown into a panic when the supply of Valender clay was exhausted. Attempts to use American clays met with failure, and enamelers were scouring the country looking for a stray pound of Valender clay. The chemical dealers immediately set about to find a substitute for this clay and are now supplying the trade with clays, good, bad and indifferent, but the report of a number of different firms is that nothing has been found to satisfactorily replace the German Valender clay.

In preparing enamels for use, the frit is ground wet with from five to ten percent of its weight of clay. There is always some flocculating agent added, generally magnesium sulphate in white and cover enamels, but in the case of ground coat

enamels borax is almost universally used. The reason for this is that nearly all other salts which act as flocculating agents cause rusting of the steel in drying the enamel and thus give trouble. Sodium carbonate can be used but is less effective than borax. Valender clay is a very clean and very plastic ball clay and gives excellent results when used in enamels, preventing settling of the frit in the dipping tubs and making the enamel easily tempered to proper consistency for dipping. The necessity for finding a substitute for it lead to this investigation.

Object of the Investigation. The object of this study was to find a clay, or combination of clays (if possible, American), which could be satisfactorily used to float enamel frits, preventing them from settling to the bottom of the dipping tub and permitting tempering to a proper dipping consistency so as to get a uniform coating of the proper thickness over the surface of the ware. The possession of a good supply of Valender clay simplified the work very much, as its action in the different tests could be used as a criterion from which to judge the value of the other clays.

Clays Tested. In considering what clays to select for test, it was thought that the ball clays were most likely to give the desired result; but the writer had on different occasions used Florida clay for this purpose, and therefore six typical clays were selected from the larger list available as follows:

No. 1 Kentucky ball clay.
No. 2 Tennessee ball clay — J. K. Porter No. 11.
No. 3 German Valender clay.
No. 4 Georgia clay.
No. 5 Florida clay.
No. 6 English ball clay M & M.

PRELIMINARY EXPERIMENT

To 20 grams of each clay was added 100 cc. distilled water, and these were shaken for one hour in a shaking machine similar to the one used by Ashley in his work at the Bureau of Standards. Immediately after shaking, the volume of each slip was noted, there being considerable difference. Named

in order of their volumes the clays are as follows: Nos. 1, 2, 3, 4, 5. Number 1 has 27 percent more volume than No. 5.

Results after standing 24 hours: Numbers 1 and 2 have no clear liquid on top but have separated in the middle of the column, showing clear water between the two columns of slip. Number 3 (Valender) has settled leaving a column of clear water over the dense slip. Total column composed of 88 percent slip, 12 percent water. Number 4 settled most giving column composed of 52 percent slip, 48 percent turbid water. Number 5 similar to No. 4, column composed of 60 percent slip and 40 percent clear water.

In this test the Florida clay acts more nearly like the Valender, but the two American ball clays show a peculiarity in refusing to settle. This might indicate alkaline clays, *i. e.* deflocculation, but there was no apparent difference between the column above and that below the water. The samples did not have the appearance of deflocculation.

Clay and Flint. Mixtures were now made using 200 grams American flint + 20 grams clay + 150 cc. distilled water. After shaking for two hours the difference in volume so marked in the last experiment is not in evidence. All slips occupy the same volume. After settling 12 hours there is again a marked difference.

TABLE I

CLAY NO.	VOLUME OF SLIP	VOLUME OF WATER
	percent	*percent*
1	88	12
2	88	12
3	97	3
4	72	28 (turbid)
5	78	22
6	97	3

This test indicates No. 4 is alkaline in character, being partly deflocculated. Numbers 1 and 6 shows superior power of holding up the flint, but the American ball clays show decided superiority over the kaolins[1].

[1] The doubtful propriety of this term is recognized, but in the absence of a better one it is used in this paper for Florida and Georgia clays.

All clays were tested to determine their relative action toward deflocculating agents, sodium hydroxide being used. Five grams of each clay were added to 100 cc. of solution consisting of distilled water plus a previously determined amount of 10 percent solution of sodium hydroxide as shown in the tables. That is, each mixture contained 100 cc. liquid containing sufficient NaOH to give the percentage indicated in the tables, percent given figured on the base of clay = 100.

The symbols used in the tables are similar to those used by Ashley[2]

S. T. = Not clear but transmits light readily through 1 inch thickness.

T = Distinctly cloudy in 1 in. thickness.

D = No granular structure visible but opaque in 1 in. thickness.

S = Opaque, and granular structure distinctly visible.

In each case the tubes were shaken for two hours, mixtures poured into a graduated cylinder, and readings taken after standing 18 hours.

The results of these experiments have little bearing on the information sought except that they show the similarity or dissimilarity of the clays. The ball clays all give very similar results, but they are quite sharply distinguished from the kaolins in that they require less alkali for maximum deflocculation. There is very marked difference between the Georgia and Florida clay in the amount of alkali required for maximum deflocculation and still greater difference in that required for re-flocculation. The Georgia clay (No. 4) shows partial deflocculation when mixed with distilled water alone, but the Florida clay does not show this. There is also a marked difference in the appearance of these two clays when at maximum deflocculation, No. 4 being very much less dense than No. 5. The latter shows a marked change in color from light cream at maximum deflocculation to rather dark brown when reflocculated. This color change may be only coincident with the increase in density, but no such phenomenon was noted in any of the other clays. On the whole, clay No. 2 is closest to No. 3 throughout these experiments.

[2] *Bull. 23, U. S. Bureau of Standards.*

TABLE II — SETTLING DATA

PERCENT NaOH	0	.2	.4	6	.8	1.0	2	3	4	5	6	7
Clay No. 1												
Clear cc.	....	....	....	....	1	....	5	....	70	73	73	73
S. T.	79	....	....	....	1	2	....	75	....	....	....	....
T.	....	2	2	3	1	1	63	....	....	....	....	....
D.	21	96	96	95	95	95	32	25	30	27	27	27
S.	....	2	2	2	2	2	0	0	0	0	0	0
Clay No. 2												
Clear cc.	76	....	....	....	3	....	41	41	41	41	55	50
S. T.	....	5	4	4	....	....	....	....	....	....	....	....
T.	....	....	....	....	42	28	....	....	....	....	....	....
D.	....	92	94	94	55	72	59	59	59	59	45	50
S.	24	3	2	2	....	....	....	....	....	....	....	....
Clay No. 3												
Clear cc.	10	....	....	....	....	....	72	77	79	79	82	81
S. T.	70	....	....	....	....	....	....	....	....	....	....	....
T.	....	2	3	3	4	3	....	....	....	....	....	....
D.	19	95	95	95	95	94	27	22	20	20	17	18
S.	1	3	2	2	1	3	1	1	1	1	1	1
Clay No. 4												
Clear cc.	88	....	....	....	....	....	....	....	....	....	....	....
S. T.	....	88	....	....	....	88	....	....	....	....	....	....
T.	....	....	88	88	88	....	....	....	....	....	....	....
D.	....	....	....	....	....	....	....	....	....	....	....	....
S.	12	12	12	12	12	12	....	....	....	....	....	....
Clay No. 5												
Clear cc.	76	....	....	....	....	....	....	....	....	....	77	....
S. T.	....	76	....	....	....	....	....	....	....	70	....	....
T.	....	....	76	....	....	....	....	....	....	....	....	....
D.	....	....	....	96	96	96	96	93	95	....	....	....
S.	24	24	27	4	4	4	4	7	5	30	23	....

Clay No.	Maximum Deflocculation *Percent NaOH*	Reflocculation *Percent NaOH*
1	.2	3.
2	.2	2.
3	.2	2.
4	.4	1.
5	.6	5.

Impure Water. A sample of enamel frit was obtained from the West Lafayette Mfg. Co., West Lafayette, O., taken from their regular stock. This was ground in a ball mill for two hours with distilled water, and the water decanted after the glass had settled. Five grams of each clay were now shaken with 100 cc. of water (50 cc. distilled + 50 cc. decanted water). The object of this was to determine whether the solubility of the enamel would render the water in which it was ground sufficiently alkaline or acid to affect the clays. The results are shown as follows:

TABLE III

Clay No.	*Volume of Slip Percent*	*Volume of Water Percent*
1	97	3
2	35	65
3	16	84
4	12	88
5	25	75
6	97	3

These readings were taken after the cylinders had stood 18 hours. Numbers 1 and 6 were completely deflocculated, while the others were still in the flocculated condition. These results cannot be very well compared with the one in which distilled water was used, because in this case only five grams of clay was used per 100 cc. water while in the other 20 grams of clay was used.

This experiment was repeated, using 50 cc. distilled water, 50 cc. enamel water, 5 grams of clay and 50 grams of enamel frit which had been ground to pass 80 mesh screen. Upon standing 18 hours the enamel settles out readily from all but decidedly most readily from Nos. 1 and 6. In case of these two

there is a sharp line between the blue enamel and the clay above. The clay has the same color as when no enamel is used, indicating that all of the enamel has settled to the bottom. The sharp division line is not present in the other, but the total volume of blue sediment at the bottom is greater than in the cases of the two mentioned, showing that the enamel has carried some of the clay down with it. The color shades off gradually from dark blue at the bottom to the gray of the pure clay on top.

These results are tabulated as follows:

TABLE IV

CLAY NO.	1	2	3	4	5	6
Clear Water cc.	0	34	50	55	45	0
Clay cc.	79	26	0	0	0	70
Gray Mix Clay and Enamel cc.	0	10	20	20	25	0
Blue Enamel cc.	21	30	30	25	30	30

In this case the kaolins are decidedly nearest to No. 3 with No. 2 somewhat similar and Nos. 1 and 6 decidedly different from all others.

To each of these cylinders was now added 1 cc. 10 percent NaOH solution, equivalent to 2 percent of the clay. After standing 18 hours no marked change from the previous condition is noted except that No. 3 now corresponds with No. 2. In this case we have three groups composed of Nos. 1 and 6, 2 and 3, and 4 and 5.

TABLE V

CLAY NO.	1	2	3	4	5	6
Clear H_2O cc.	0	32	30	50	50	0
Clay	80	38	40	20	20	75
Gray Mix Clay and Enamel	0	10	10	10	10	0
Blue Enamel	20	20	20	20	20	25

In this case Nos. 1 and 6 are quite completely deflocculated and still show the sharp line between clay and blue

enamel. Numbers 2 and 3 show some deflocculation but decidedly less than the kaolin Nos. 4 and 5. This agrees with the previous results on deflocculation.

The results of the tests with the water from enamel indicate that although the tendency is distinctly to deflocculate the clays, still the effect is not very great except in the case of Nos. 1 and 6 where the result was sufficient to distinguish these clays plainly from the others.

It must be borne in mind that these preliminary tests were not designed with a view to obtaining satisfactory enamel slip but simply to study the character of these clays and determine, if possible, which of them was closely related to the German Valender clay.

Correlating these results we find that in distilled water alone, Nos. 3 and 5 are similar, with Nos. 1 and 2 somewhat similar to them. Table I shows Nos. 3 and 6 most nearly alike with Nos. 1 and 2 again somewhat similar to them.

Table II, Nos. 2 and 3 similar, with No. 1 somewhat like them.

Table III, Nos. 3 and 4 similar, with Nos. 2 and 5 somewhat like them.

Table IV, Nos. 3, 4 and 5 similar, with No. 2 somewhat like them.

Table V, Nos. 2 and 3 similar, with Nos. 4 and 5 somewhat like them.

According to this summary, there are some respects in which all the clays are similar to No. 3, but a summation of the results places the clays in the following order as regards their resemblance, to No. 3, viz. Nos. 2, 5 (1 and 4) 6.

DIPPING SLIPS

Attempts were now made to determine how the clays would act when used as the agent for floating the frit in enamels.

There are five factors which greatly influence the floating of the frit in enamels or glaze, namely:

1. Size of grain of the frit.
2. Specific gravity of the frit.

3. Concentration of solid in the slip, i.e. amount of water added to the solid.
4. Viscosity of the floating medium.
5. Amount of the floating medium.

1. Fine grinding makes the frit more easily floated, but enamelers dare not grind too fine because they can not get a uniform coating over the surface of the ware. Ground coat enamels especially must be coarse, not finer than 100 mesh and better 80 mesh.

2. No discussion of this seems necessary. Lead enamels would of course be more difficult to float than lighter ones, but lead is seldom used in enamels for sheet iron. However all frits are relatively high in specific gravity compared to clays.

3. Settling is easily prevented by making the slip thick, approaching a paste, but in order to apply slips by dipping or spraying they must be fluid to a sufficient extent to flow, and when they have this consistency, settling of the heavier substances results unless prevented by some agent.

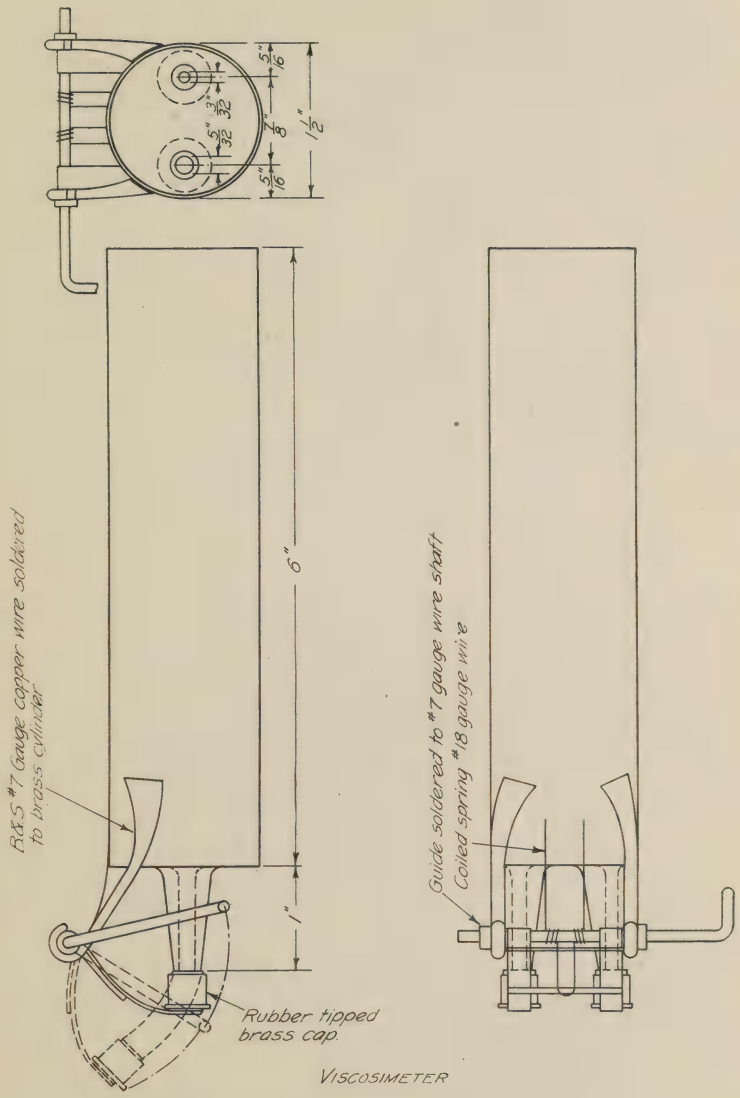
4. Viscosity has been described as the friction between liquids flowing in contact with one another or between a liquid and a solid moving in it. This means resistance to flow. From this it will be seen that the ability of a floating medium to prevent the settling of the heavier particles depends upon the resistance which it offers to their motion in passing through it. That is, the efficiency of a floating medium depends upon its viscosity. The term floating medium as used here does not mean water but the agent which serves to prevent solids from settling out of the water, in this case clay substance.

5. It is evident that a sufficient amount of floating medium can be added to prevent settling, but other considerations limit the amount of clay that can be used in any glaze or enamel, and in the latter ten percent is about the maximum permissible. Therefore the efficiency of the clay in floating the frit is highly important. This is more so in enamel than in glazes or engobes because enamel frits are higher in specific gravity and more coarsely ground than the material of fritted glaze or engobe, and the amount of clay used in essentially small.

Viscosity. It follows from these considerations that the viscosity of the enamel slip is a very important property. A high viscosity can be obtained by high concentration of solids in the slip, but this has been shown to be not permissible. A high viscosity in enamels is necessary to prevent the slip from flowing down the sides into the corners of the ware after dipping. A steel body being non-absorbent, the problem here is quite different from the one of dipping a porous clay body into a glaze. The absorption of the clay prevents flowing of the glaze, but in the case of the steel body the slip must stay where it is put by virtue of its viscosity, though it is possible that surface tension plays an important role here also.

In view of these facts, great emphasis was placed on the viscosity in testing these slips, and considerable time was spent in finding a viscosimeter that answered the purpose. Someone has said there are as many types of viscosimeters as there have been investigators of viscosity, and the writer is no exception to the rule. After trying a number of different types the viscosimeter shown was devised. It gave excellent results throughout this work, and it is believed that enamelers would profit by the use of something similar to it in keeping their slips of uniform consistency. It is not impossible that it would be of value in making up glaze and engobes. It is very simple to make and use, and the error in careful work will be less than two percent. The one shown cost $2.85 complete. The essential parts of the apparatus are two brass tubes one inch long and $^{3}/_{32}$ in. and $^{5}/_{32}$ in. diameter respectively. The caps are held over the bottom ends of the tubes by a spring. A graduate is set under each tube when ready for use, and the spring is released allowing the slip to flow through the tubes into the graduates. The only reading required is the volume of slip which has flown into each graduate. The determination of the viscosity is based on the following consideration. The formula for the quantity of liquid flowing through a pipe is as follows: $Q = K A \sqrt{2gh}$ or quanity $= K \times$ *Area of tube* $\times$ *Velocity or head.* K is a constant for a given tube and liquid and depends upon the friction or resistance to flow.

TRANS. AM CER. SOC. VOL. XIX. FIG. 1. SHAW



VISCOSIMETER

In the viscosimeter there are two tubes, *a* and *b*.

For a, $Q_a = K_a A_a \sqrt{2gh}$ (1)

For *b*, $Q_b = K_b A_b \sqrt{2gh}$ (2)

Dividing (1) by (2) $$\frac{Q_a}{Q_b} = \frac{K_a}{K_b} \frac{A_a}{A_b} \frac{\sqrt{2gh}}{\sqrt{2gh}}$$

or $$\frac{K_a}{K_b} = \frac{Q_a}{Q_b} \frac{A_b}{A_a} = Kx = \text{Viscosity}$$

Take a concrete example, with water in this apparatus,

Viscosity = 3.00

$Q_a = 45$ cc.

$Q_b = 15$ cc.

$\therefore \quad 45 \text{ cc.} = K_a A_a 2 gh$

$15 \text{ cc.} = K_b A_b 2 gh$

dividing

$$\frac{45}{15} = \frac{K_a}{K_b} \frac{A_a}{A_b}$$

$$\frac{K_a}{K_b} = 3 \cdot \frac{A_b}{A_a}$$

$\frac{A_b}{A_a}$ remains constant and need not enter the calculation so long as all determinations are made with the same apparatus.

It is general practice to refer viscosities to water as unity, but since no two viscosimeters give the same value for water, it seems just as logical to refer the results to the apparatus itself, and that was done in the following determination.

The settling was determined by pouring the slip, after shaking, into 100 cc. graduates, allowing to settle 18 hours, reading the volume of water on top of the slip, weighing cylinder and slip, decanting water from the top and weighing cylinder and sediment, decanting the upper half of the slip, weighing graduate and the remaining slip, cleaning the cylinder and weighing empty. Having the volume and weight of the slip, the specific gravity was found by dividing weight by volume.

The Slip. In the first series the procedure was to grind the frit dry to pass 80 mesh screen. The slip was then com-

pounded by weighing the frit and clay dry and adding the required amount of water and flocculating agent in solution, shaking the slip for two hours and allowing to stand for 18 hours before testing. The slip in this series consisted of 100 grams frit, 100 cc. of water and 5 percent magnesium sulphate, plus the required amount of clay.

In Series 2 the slips were made up without flocculating agent and ground wet through 80 mesh screen, after standing 18 hours they were tempered with water and flocculating agent as shown in the table. They were then shaken by hand for one minute and tested immediately for viscosity. Samples of these were poured into graduates for a settling test.

Before deciding upon the amount of flocculating agent to use, a series was run with each clay, using 9 percent clay and 50 percent water (based on the frit) and aluminium sulphate as flocculating agent varying (.1 percent, .5 percent and 1 percent). The viscosity of these was determined as shown in Table VI.

TABLE VI

CLAY NO.	$Al_2(SO_4)_3$	SP. GR. OF SLIP	VISCOSITY $= Qa + Qb$
	percent		
No. 1	1.0	1.54	6.25
No. 2	.1	1.51	7.14
No. 2	.5	1.48	4.75
No. 2	1.0	1.49	5.55
No. 3	.1	1.47	3.85
No. 3	.5	1.48	4.35
No. 3	1.0	1.49	4.35
No. 4	.1	1.48	4.35
No. 4	.5	1.50	5.10
No. 4	1.0	1.50	5.26
No. 5	.1	1.49	4.17
No. 5	1.0	1.49	4.17

These results indicate that the amount of flocculating agent does not affect the result very much, provided a sufficient amount is added to flocculate the clay. The maximum and minimum points noted by others in studying this problem are no doubt here obtained, but in this case where the amount of clay is so small in proportion to the total slip the difference in viscosity is not of any consequence. Therefore it was decided that no

great error would be introduced by using the same amount of flocculating agent in each slip. The amount decided upon was that which is ordinarily used in commercial practice.

The results are shown in the Tables and Figures. The clay No. 7 was added to the list after most of the preliminary work had been done. It is a clay which is being supplied to the trade, and the dealers claim it to be very satisfactory. It looks very much like Florida clay and corresponds very closely to No. 5 in every respect. In the second series clays No. 4 and 6 have been dropped and No. 7 added.

Table VII shows that with low clay content No. 3 is superior to all others with No. 2 and No. 1 not much inferior. Numbers 4, 5 and 6 are decidedly inferior in floating power judging from the differences in specific gravity of upper and lower half of the slip.

TABLE VII. SETTLING OF ENAMELS MADE AT DIFFERENT SP. GR. WITH VARIABLE AMOUNTS OF DIFFERENT CLAYS

.5 Percent $MgSO_4$ Constant
Series 1.

CLAY NO.	CLAY *Percent*	WATER ON TOP *cc.*	ORIGINAL VOLUME *cc.*	ORIGINAL SP. GR.	SEDIMENT SP. GR.	LOWER HALF OF SEDIMENT SP. GR.	DIFFERENCE
1	1	1.75	50	1.37	1.56	1.62	.06
2	1	1.75	50	1.36	1.56	1.62	.06
3	1	18	50	1.38	1.56	1.64	.05
4	1	19.5	50	1.36	1.56	1.64	.08
5	1	20	50	1.38	1.60	1.79	.19
6	1	19.5	50	1.36	1.59	1.91	.22
2	2.5	14.5	50	1.40	1.57	1.58	.01
3	2.5	15	50	1.39	1.56	1.57	.01
4	2.5	16.5	50	1.39	1.58	1.63	.05
5	2.5	17.5	50	1.38	1.58	1.67	.09
6	2.5	15.5	50	1.42	1.56	1.65	.09

Table VII shows somewhat different when judged on the same basis as the above but it will be noted that the water on top of the slip indicates that here also Nos. 2 and 3 are superior. They have settled less than the others, and this condition would tend to facilitate settlement of the frit, the larger volume of slip proper (called sediment in the table) decreasing its density.

Therefore the apparent difference in favor of Nos. 1, 5 and 7 as shown by the (difference) column is not all real.

TABLE VIII

Series 2.

CLAY NO.	CLAY *Percent*	WATER ON TOP *cc.*	ORIGINAL VOLUME *cc.*	ORIGINAL SP. GR.	SEDIMENT SP. GR.	LOWER HALF OF SEDIMENT SP. GR.	DIFFERENCE
1	8	9.5	50	1.49	1.60	1.66	.06
2	8	7	50	1.49	1.56	1.67	.11
3	8	6	50	1.46	1.52	1.60	.08
5	8	9	50	1.51	1.63	1.60	—.03
7	8	9	50	1.49	1.59	1.62	.03
1	8	4.5	50	1.50	1.61	1.61	.00
2	8	4	50	1.58	1.63	1.71	.08
3	8	2.5	50	1.57	1.59	1.69	.10
5	8	6.5	50	1.56	1.63	1.61	—.02
7	8	5.5	50	1.54	1.61	1.64	.03

One point of interest in Table VIII is the "difference" in case of No. 5. The minus sign means that the upper half of the sediment is heavier than the lower half. The same relative result is obtained in two different cases, with different specific gravity of the original slip. No explanation of this is offered.

The settling data, as a whole, points to No. 2 as nearest to clay No. 3, but the kaolins show a surprising power of preventing sedimentation. It must be said, however, that the conditions here are not exactly what are encountered in commercial practice. The slip in dipping tubs is continually stirred, and this has the effect of washing out the heavier particles and facilitating sedimentation as soon as the stirring ceases. This phenomenon was noted in these experiments and has often been noted in practice. Occasional stirring of the slip on top causes the frit to settle to the bottom leaving clay on top.

The viscosity curves represent graphically the relative values of these clays for enamel purposes. The curves tell their own story, and the results are quite sharply defined. Enamels must have a high viscosity with a low weight per cc. From Figure 2 it is evident that the ball clays are far in the lead, and clay No. 2 is as good or better than No. 3.

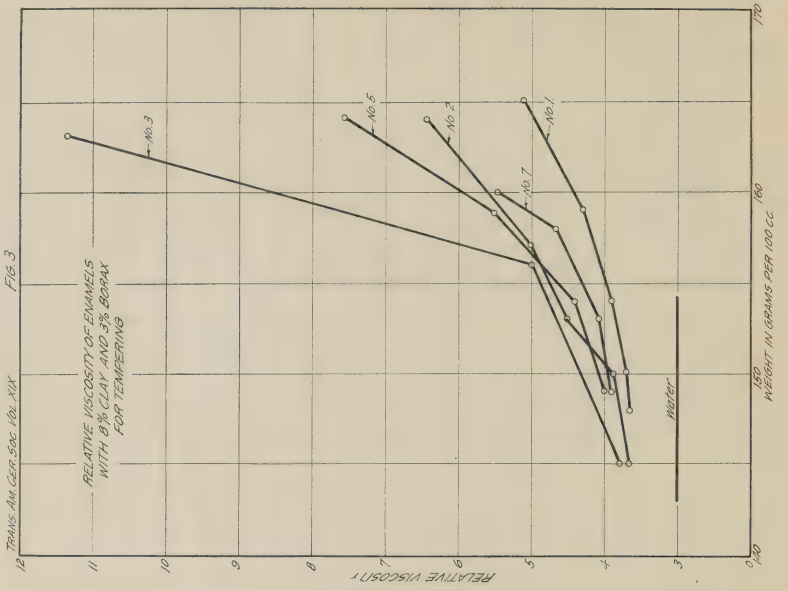


FIG. 3
TRANS. AM. CER. SOC. VOL. XIX
RELATIVE VISCOSITY OF ENAMELS WITH 8% CLAY AND 3% BORAX FOR TEMPERING
No. 3
No. 5
No. 2
No. 1
No. 7
Water
RELATIVE VISCOSITY
WEIGHT IN GRAMS PER 100 CC.

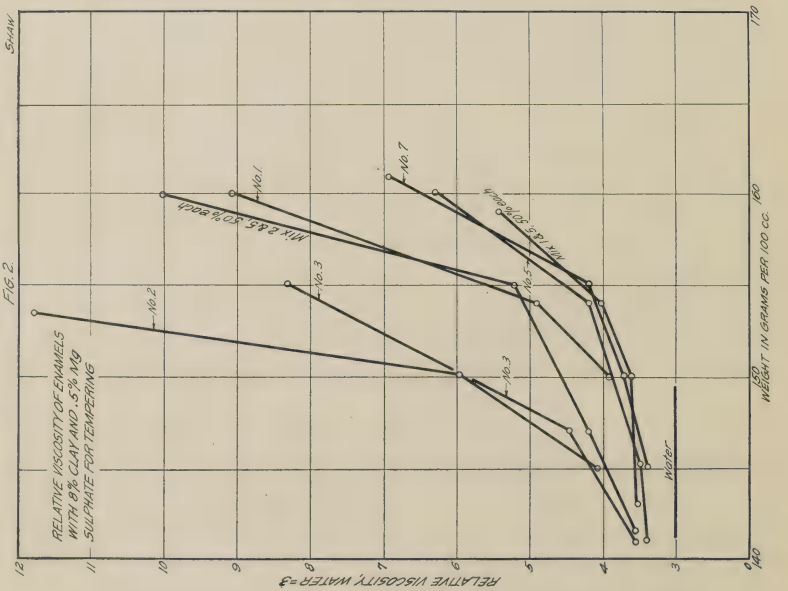


FIG. 2
SHAW
RELATIVE VISCOSITY OF ENAMELS WITH 8% CLAY AND .5% MG SULPHATE FOR TEMPERING
No. 2
No. 1
No. 7
No. 3
No. 3
Water
RELATIVE VISCOSITY WATER = 3
WEIGHT IN GRAMS PER 100 CC.

Clay No. 1 shows well but decidedly inferior to a mixture of 2 and 5, half and half. Figure 3 shows clay No. 3 decidedly in the lead and No. 5 (Florida) a little better than clay No. 2. This sheet represents actual factory practice, and it is in the enamel tempered with borax that most trouble comes.

Comparing Figures 2 and 3 it will be noted that in Figure 2 a very high viscosity is obtainable with weight of slip as low as 154 grams per 100 cc., but in order to get these viscosities, as in Fig. 3, the weight per cc. must be increased to about 162 grams per 100 cc. This heavy weight per cc. makes it very difficult to distribute the enamel over the ware and also makes the enamel tend to flow down the vertical sides of the ware because of its specific gravity. The high specific gravity tends to overcome the viscosity which prevents flowing.

For these reasons enamelers in tempering their enamel aim at a certain value of viscosity as related to weight per cc. This is learned by practice and is very much the same as tempering clay in a pug mill. There is no mathematical expression for this value, and so far there has been no attempt made to fix upon it, but the relation is shown on these curves.

Examining Fig. 4, it will be noted that where no flocculating agent is used a maximum viscosity of 6.5 for these clays is obtained at a weight of 174 grams per 100 cc., and at 160 grams the viscosity in all cases is down near that of water. Even with this viscosity of 6.5, which is the maximum obtained, these slips will run down the sides of the ware; but where tempering agents are used giving viscosities of 6.5 at much lower weight per cc. the enamel does not flow down the sides. Viscosity as low as 4.5 is permissible provided the weight per 100 cc. is not far above 150 grams. Comparison of Figures 2, 3 and 4 shows not much relative change in the positions of the clays, but there is a decided difference in the efficiency of flocculating agents. Figure 5 gives a comparison of the three clays which were selected as the best of those tested:

Clay No. 3 (Valender) is decidedly superior.

Clay No. 2, Tenn. ball clay, next to No. 3 and in some cases superior.

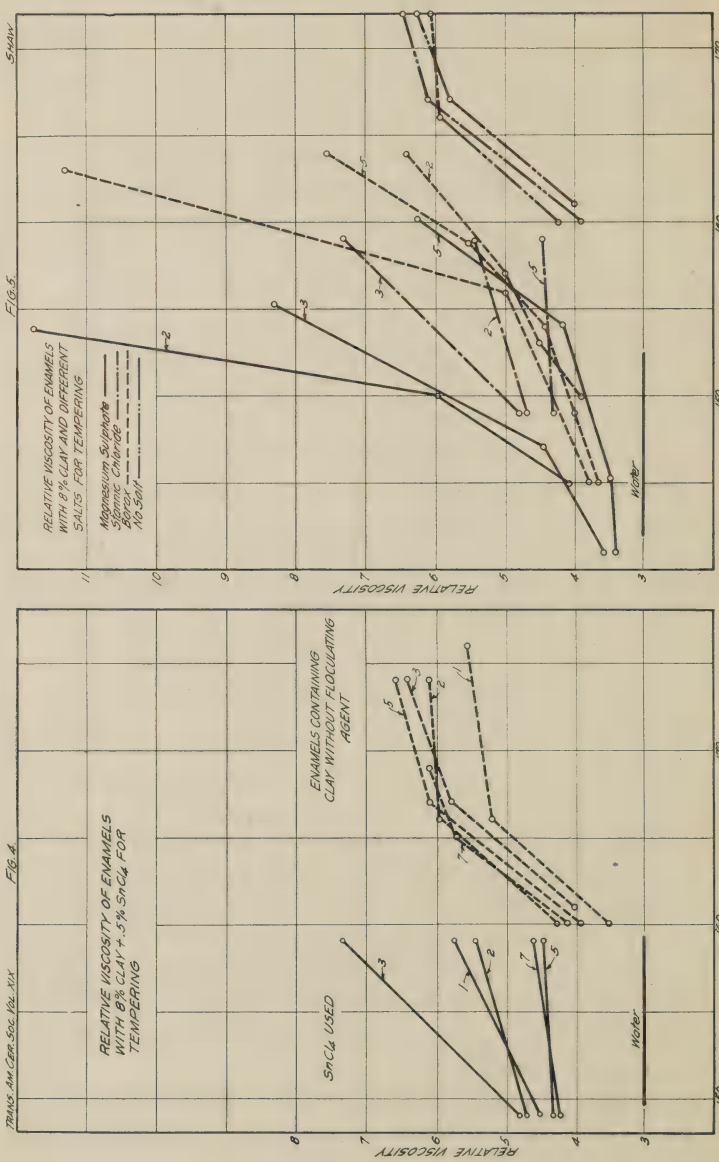


FIG.5.
RELATIVE VISCOSITY OF ENAMELS WITH 8% CLAY AND DIFFERENT SALTS FOR TEMPERING
Magnesium Sulphate
Sodium Chloride
Water
N/10 Salt
RELATIVE VISCOSITY
WEIGHT IN GRAMS PER 100 C.C.
TRANS. AM. CER. SOC. VOL. XIX
FIG.4.
RELATIVE VISCOSITY OF ENAMELS WITH 8% CLAY + .5% SnCl4 FOR TEMPERING
ENAMELS CONTAINING CLAY WITHOUT FLOCULATING AGENT
SnCl4 USED
Water
RELATIVE VISCOSITY
WEIGHT IN GRAMS PER 100 CC.

Clay No. 5, Florida clay, next and surprisingly good for the purpose intended.

Conclusions. There has been a vast amount of work done in devising some method of measuring the plasticity of clay but as yet no satisfactory method of obtaining an expression for plasticity in mathematical terms has been found.

The work undertaken in this study involved a problem of precisely the same nature, but it was simplified somewhat because the material studied was fluid rather than plastic. Still the thing that had to be measured was the consistency of the enamel. This term consistency corresponds quite closely to plasticity of clay and like the latter has always been judged by the sense of feeling. The enameler can take his can of salts and a bucket of water, and if the enamel is not already too thin he can temper it up just to suit him.

While this is good, it is unscientific, and where exact standards are obtainable they are given preference in this scientific age.

It is believed that the results obtained in these experiments have accomplished two things.

1. An American clay has been found that ranks fairly well with the German Valender clay when used in enamels. Furthermore, it has been shown that because a clay is a ball clay it does not necessarily follow that it is good for floating enamels and glazes. Florida clay is better for this purpose than Kentucky ball clay or English M and M.

2. A simple method has been devised for measuring the viscosity of enamels and the relation between the viscosity and specific gravity (which can be determined approximately by weighing a known volume) gives a value which represents the consistency.

By using this value enamels or glazes or slips can be kept constant and thereby more nearly uniform results obtained.

DISCUSSION

Mr. Denmead: I should like to add a word to the discussion of this paper. We have been through this same thing in our enameling plant at Schenectady, and did not find any of

the clays satisfactory that Mr. Shaw advises. We found clays of a very peculiar nature and source that were very satisfactory, and it might be of interest to some members of the body to know the names of these clays. We found an air floated clay from Harbison and Walker, and a glass pot clay from William Govels. These were excellent for ground coats. We found a "gold" clay (termed so by Rossler and Hasslocher) to be very fine for the other coats. Mr. Smith may tell us what "gold" clay is.

Mr. Smith: I have nothing to say except that it comes from Florida. If anybody wants a test, they can try it.

Mr. Brown: I would like to ask Mr. Shaw whether he found a difference between the Tennessee ball clay and the Valender clay, insofar as the color of the white enamel is concerned? Also whether he found that the Tennessee ball clay contained impurities, such as lignite, which would tend to introduce black specks into the white enamel?

Mr. Shaw: That is one disadvantage to some extent. The Tennessee ball clay is much better in that respect than other ball clays, but it does contain more carbonaceous matter than the Valender clay, by far. One of the great virtues of the Valender clay is its great purity. That would not affect the results so far as the ground coats are concerned, but in white enamels, there would be some disadvantage. I do not claim that the Tennessee ball clay is as good as the Valender clay. None that I tested were as good as the Valender clay for that purpose, but the Tennessee ball is the nearest to it.

Mr. Staley: I would like to ask Mr. Shaw whether these clays were clays free from organic and oily matters? In trying to use ball clays, I found that a good many seemed to have a sort of oily matter that interfered in floating enamels evenly onto metal. I have used Florida clay which seemed to work very satisfactorily. I thought that was due to the absence of any form of organic matter in the Florida clay.

Mr. Shaw: I think that is the question I answered last. There is some organic matter in the Tennessee clay and in the Kentucky clay that would tend to be injurious, but the Tennessee clay can be used in enamels with good effect.

Mr. Staley: What is the number of the clay?

Mr. Shaw: Number 11. Florida clays can be used too, but they are not as good as Tennessee ball clay.

Mr. Poste: I have one question that is a little bit aside the question. Mr. Shaw made a comparison or insinuated a comparison between the relative merits of the magnesia, borax and tin chloride. I was wondering if you made the comparison based on the same percentage of vehicle present or did you compare magnesium sulphate and borax, based on chemical equivalents of the two substances?

Mr. Shaw: I did not go into details to describe that in the paper. I determined first the amount of each of these ingredients that would give the maximum viscosity of enamels. The amount of magnesium sulphate used was 5 percent. There are maximum and minimum points, but, as applied to enamels where there is only 10 percent of clay in the mix, it does not affect the viscosity to such a great extent as in the case of pure clay. I made tests to determine how much of each of these flocculating agents I would need to add in order to get maximum viscosity. In the case of magnesium sulphate, I used 0.5 percent of the weight of the frit; in the case of the borax, I used 3 percent, and in the case of the tin chloride, I used 0.5 percent. The amounts used were all determined beforehand so that they would give maximum results.

Mr. Beecher: What was the density of the Kentucky ball clay used?

Mr. Shaw: Can you tell me that, Professor Binns?

Mr. Binns: Mandle's Number 1.

Mr. McDougal: Did Mr. Shaw find that the definite quantity of magnesium sulphate used, 5 percent, gave him a maximum flocculating effect, no matter which clay was present in the enamel?

Mr. Shaw: Yes, that is approximately correct. The experiment is in the paper showing those results. I ran that through on all clays, varying the amount of each of these flocculating agents in all the clays. It varies somewhat, but the difference is so small that no appreciable error was introduced

in using a constant amount of these flocculating agents in each one of these clays.

Mr. Binns: I want to correct a statement that I made just now by a slip of the tongue. That clay that was asked about, the Kentucky clay, is not Mandle's, it is the clay of the Kentucky Construction and Improvement Company, I think it is Number 6, Mandle's is the Tennessee clay.

NOTES ON THE MANUFACTURE OF PROMENADE TILE

BY MARION W. BLAIR, M. E.

In 1912 Mr. W. H. Gorsline of Rochester, N. Y., presented to this Society a paper discussing some of the difficulties encountered in the manufacture of stiff-mud floor tile, (now generally designated as "promenades" if 6 in. by 9 in. or "quarries" if 6 in. by 6 in.) and the methods used to overcome them.

Since that time the writer has spent nearly four years in a plant making such tile, endeavoring to improve the methods of manufacture. While many of the difficulties encountered were similar to those already described, the solution was worked out independently and in most cases by another route. The addition of this experience, therefore, to the Society's records may not be amiss.

The plant in question is located in the northern part of Pennsylvania and was the outgrowth of a side line produced in a brick plant nearby, whose experiments were by no means conclusive. Yet the new plant was built to manufacture tile or, as the promoters gave out, brick if the tile should prove a failure.

The design followed essentially brick-plant ideas, and as a result the manufacture of tile had to be adapted to brick-plant design both in machinery and kilns, as well as to the use of a brick shale without the admixture of other clays. Correct engineering would have dictated a design suitable to the product: smaller kilns, more compact machine room, molding rooms and controlled drying facilities. The first year's operation resulted in failure and financial loss, and the reorganized management was well on toward the end of its first year when the writer became interested in the plant and its production. At that time the demand for tile was beyond the supply, while brick were difficult to move at any price. The problem then was to make a marketable tile with the equipment at hand, consisting of power

plant, dry pan, inclined gravity screen of perforated metal, pug mill, small auger machine, two tile cutting tables of the Bensing type, a gas-fired direct-heat dryer and eight gas-fired, thirty-foot, round, down-draft kilns.

The hollow-tile method with the corners scored had already been tried and abandoned, and tile were then being run on an oil lubricating die in a single column. They were faced on the off bearing belt, and the pairs hacked one deep on rack cars with wooden pallets. The hackers used a wide trowel to lift the tile from the belt to the pallet.

Owing very largely to avoidable mechanical defects, less than thirty percent of the tile made were in a fit condition to ship, and that thirty percent would not go in the market today as second grade.

Among the defects found in the 6 by 9 tile were roughness of surface due, in part, to crumbs of clay sticking to the surface of the column and caught between the faced tile. Side checks or cracks varied from a hair line a fraction of an inch in length to an open crack half way across the tile. Blisters were frequent and on breaking down, left a rough, irregular hole in the tile's surface. There were many irregularities of length between separate tile and inequalities of length in the same tile. Ends were both concave and convex, and many tile were simply out of square. This is descriptive of the thirty percent going to the stock piles. The other seventy percent were going to the dump as bats.

The tile were set on the flat, twenty-four high, with eight to twelve green brick under them. No boxes or saggers were used. The problem was to increase output and decrease breakage, as well as to improve quality. It was soon discovered, in fact already known, that the breakage occurred in the dried tile before the kiln was fired. The cracking of the tile in the lower courses could be distinctly heard as the weight increased with the placing of the upper courses. The side check, however, was not entirely a result of weight, as that defect appeared in the upper courses of the kiln where they were free from weight. The bats were attributed to three principal causes: First, some rupture of bond in the clay column; second, warp in the dryer;

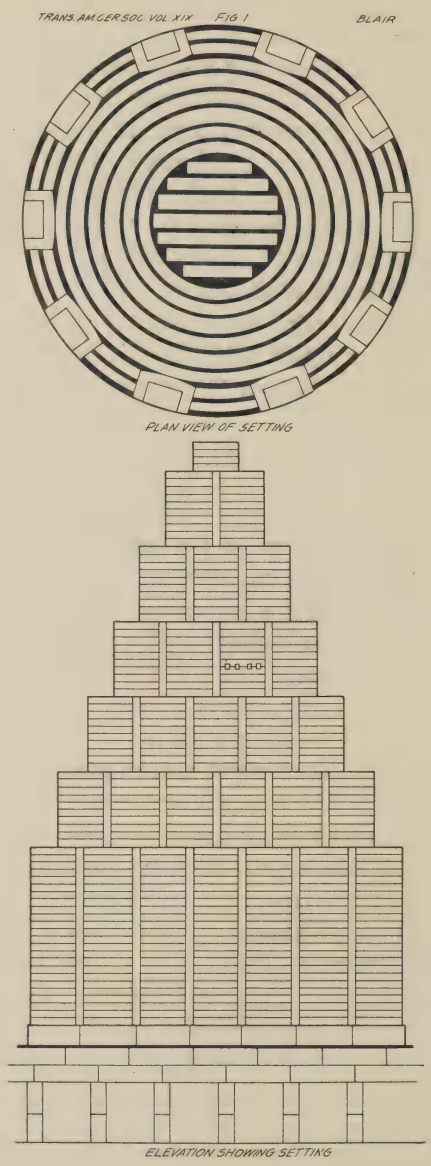
third, the weight on the warped though unbroken tile. It was concluded that the warp was increased by the rupture, that the elimination of the latter would lessen the former, and further that the elimination of both would lessen the effect of the weight. It followed that correction must begin at the machine.

It was found that the clay column was being allowed to sag and also move sidewise between the mouth of the die and the cutting table, which accounted for a part of the ruptured column. A steel plate with angle side guides bolted to the mouth of the die corrected the trouble at that point. In the process of facing the tile, crumbs would often break one tile or both. The flopper would also bend the upper tile slightly, and if the pair was dried with the bend in the tile, the upper one would often break under additional weight.

A low pressure blower blowing through a two-inch pipe across the column between the cutting table and the flopper eliminated the crumbs of clay. Its installation was not expensive as it was picked out of the junk pile. Its value to the plant was many thousands of dollars.

A brass roller about five inches in diameter, weighing about twenty pounds, keyed to a shaft with spindles turned down to one-half inch and suspended over a steel plate placed under the off bearing belt just high enough to ride a pair of tile if they presented a hump but to remain stationary if the pair happened to be straight, put all tile straight and in perfect contact. These two devices more than doubled the amount of whole tile.

We began to increase the number of tile to the kiln, setting the tile higher and leaving out some of the brick courses. Too high a percentage of warped and consequently broken tile persisted, due to the single hacking and wooden pallets. Therefore steel pallets with separating lugs for air circulation were tried out in a small way, and their apparent success led to the complete equipment of the cars and the wood pallets were discarded. A certain amount of warp still persisted, and blisters sometimes appeared, causing a loss of nearly forty percent. In the meantime the manufacture of brick for the bottoms of the kilns had been stopped, and burned brick in less quantity were used over and over. This left out of service a number of double-deck


TRANS. AM. CER. SOC. VOL. XIX FIG. 1
BLAIR
PLAN VIEW OF SETTING
ELEVATION SHOWING SETTING

brick cars which could only be used for tile by placing them in vertical stacks twelve or fourteen high on each deck. It soon became apparent that while the tile on these cars dried very slowly they were comparatively free from both warp and blister. Pallets were removed from the rack cars, allowing similar stacking on them. We were soon able to increase the height of the setting, finally maintaining seventy-eight as the standard setting. In such a kiln some four thousand tile were used as ties and, including these, a kiln losing less than ten percent in bats was not uncommon.

Various combinations — groupings and arrangements — in setting were tried. At one time the bottom courses were set on edge which reduced the breakage but so increased the number of off grade tile due to kiln warp that it was abandoned. Fire clay slabs were introduced at different points, but except in burning shapes, the boxes or slab and stilt method used at some plants was studiously avoided. This was done because it was felt that a mechanically correct tile had sufficient strength to support the weight necessary to be put upon it and that the increased kiln capacity, labor and fuel saving would more than justify a slight loss in bats. Our final choice of setting was as shown in Fig. 4.

Two brick faced, on which were two on the flat, were used in the bottom; between the top brick and a 7 by 10 by 2½ fire-brick slab was placed a leveling strip of green clay. The slabs were thus brought to a definite and uniform level each burn, without regard to any slight differences in the kiln bottom. On these fire-brick slabs was placed a double twelve stack of tile. The top pair were removed from the stacks as they came through the dryer on account of unavoidable warp and those four tile were placed on top of the setting where they would not be subject to weight. Staggered on the twenty-four were placed five tens and a four, making the setting seventy-eight high.

At the same time that the experiments described in straightening, hacking and setting were being carried on, many slight changes were made in the die, trying to overcome the shrinkage defects due, as Gorsline points out, to a differential flow of the clay. Believing that the oil lubricated die could be worked out successfully, all our efforts were concentrated on that type. The

die used is of the cork in bottle type, with a single scale or oil ring at the back. The die itself was of gray cast iron machined all over. Starting with a die three inches long, it was gradually increased until the final length was roughly equal to the width of the column. The construction is shown in Figures 2 and 3.

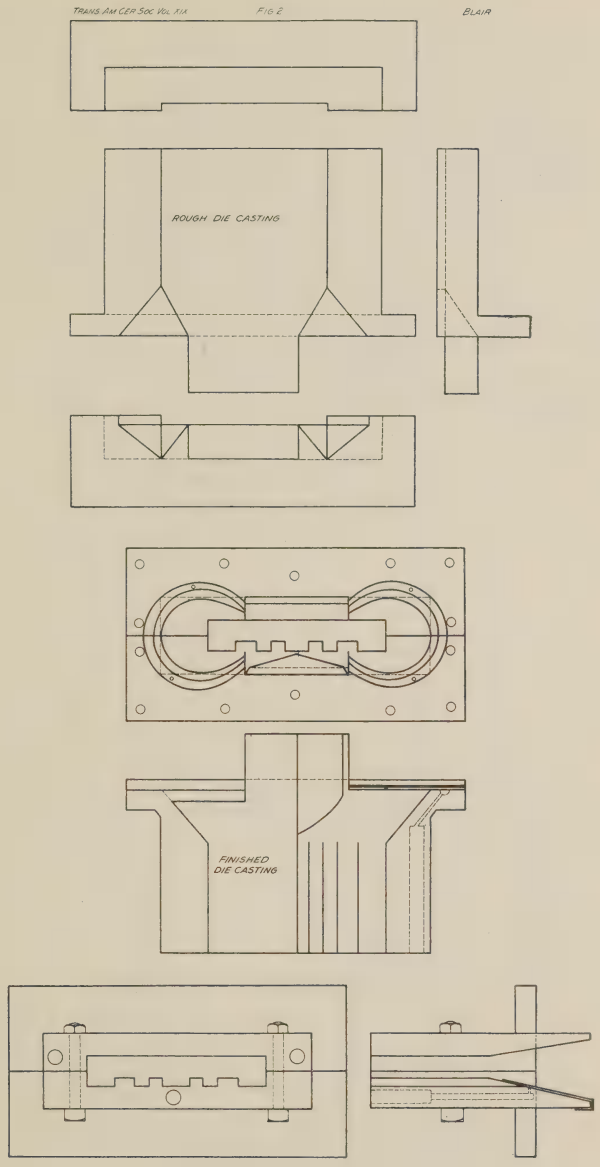
Starting with a lubrication obtained by a steam pressure of forty to sixty pounds, we finally resorted to air pressure of two hundred twenty-five to two hundred fifty pounds, the lubricator shown being installed to handle it conveniently.

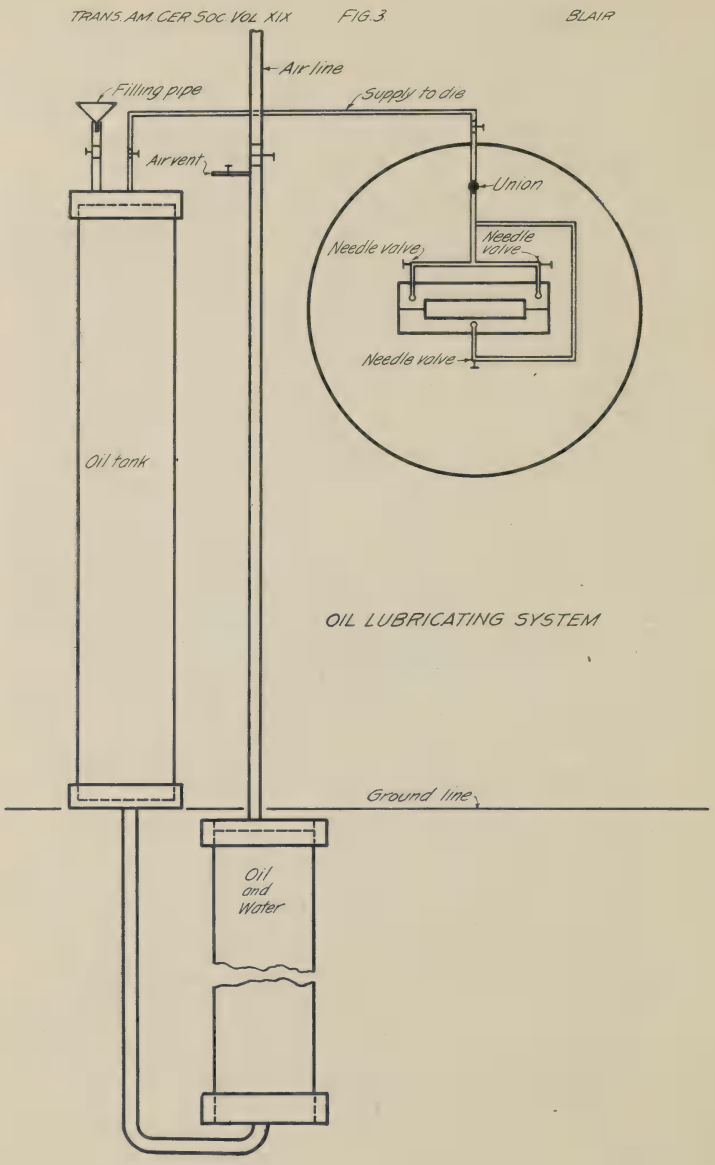
Experiments in the distribution of clay by means of ribs were also made, holding, however, to the original sizes and weights. The different arrangements are shown and the value of the present design will readily be seen.

Double dies were tried — both those running the tile face to face and those running them back to back. Neither style was satisfactory, as it was impossible to preserve a perfect face on both the top and bottom tile. Coming back to the single die, its bad features were gradually eliminated. Blisters disappeared as we increased the weight of the drying stacks. The concave and convex ends disappeared with better controlled lubrication.

As the quality increased, the exactions of the trade grew apace. Each tile was inspected carefully before going to stock or car. This inspection was found to be done best outside the kiln, so after cooling the tile were drawn in zones for shade and taken to a sorting bench to be graded for size and quality. Contrary to expectation we had little difficulty in separating the tile from the lower courses. No sand was used, and the ready separation was no doubt due to the tough skin surface produced under the pressure employed. It is also probable that the surface became slightly impregnated with the oil used, which would lessen its tendency to stick. It is at least interesting to note that brick made of the same material, set without sand, was not a success.

Other sizes up to 12 in. by 12 in., as well as many special shapes, such as coves and nosings, were run through dies similarly constructed. Shapes with re-entrant curves and angles were made on a hand press, using molds with white metal fillers. It was very difficult to prevent blisters on surfaces which were


TRANS. AM. CER. SOC. VOL. XIA
FIG. 2.
BLAIR
ROUGH DIE CASTING
FINISHED DIE CASTING


TRANS. AM. CER SOC. VOL. XIX FIG. 3 BLAIR
Air line
Filling pipe
Supply to die
Air vent
Union
Needle valve
Needle valve
Needle valve
Oil tank
OIL LUBRICATING SYSTEM
Ground line
Oil and Water

exposed to drying conditions. No doubt a lack of properly controlled drying rooms was largely responsible for such results.

Variation in size is still the source of considerable complaint, and this could no doubt be helped by the introduction of refinements in the selection and preparation of raw materials but, like the manufacture of many other clay products, the low prices and the growing competition make questionable the wisdom of increased investment and manufacturing costs.

If it were possible to accumulate the experiences of several manufacturers and so design a plant and so select its location as to raw material, fuel and market as to avoid the costly experimental work of the first few years' operation, the manufacture of promenade tile could be made interesting, pleasant and profitable.

IN WHAT CHEMICAL CONDITION DOES MANGANESE EXIST IN GLASS WHEN USED AS A DECOLORIZER, AND WHAT FACTORS OF FURNACE CONDITIONS AFFECT IT?

DISCUSSION

Mr. Frink: Anyone who is acquainted with glassmaking and glassmakers, knows that it is a fixed and prevailing idea among them that certain furnace conditions will, if produced over any considerable period of time, bring about a condition of color in the glass which is termed as "burning out" of the manganese, thereby producing green glass. What occurs within the furnace to produce that condition which negatives the effect of the manganese is as yet, I believe, unexplained or unaccounted for. It is presumed by some that this burning out occurs because of too sharp, or too high oxidizing fire, by others because of too soft or reducing fire.

I may cite an instance of where a furnace was run with the use of 4½ pounds of manganese to the 1,000 pounds of sand over a long period of time, and made glass of good color. When this factory experienced trouble with their color, they gradually increased the manganese until they were using 20 pounds to the 1,000 of sand, but instead of producing the white glass desired they could only obtain a dark green color. Analysis of the other batch constituents showed no material change between the quantity of iron present in the raw materials in the last instance from what was present in the first instance.

Therefore, it would seem that furnace conditions are solely responsible, and it has been proven that reducing gases within the furnace will produce the green color, complete oxidizing conditions a clear water-white, while a neutral or inert condition produces a pink to a violet tint, but in what form does manganese exist in the finished glass under these conditions of color, and what is required to produce them?

It has also been stated that as the lime and magnesia content increases as related to the silica in the glass, the effect of manganese becomes more pronounced and sensitive to fire conditions, while the higher the soda content in the glass as related to silica the less effective becomes the manganese, but the more stable is the color under certain specific furnace conditions.

Therefore, what factors of furnace operation become effective, and how shall we control those factors so as to produce uniform color with different compositions?

Mr. Frink: Here is a problem on which, perhaps, the porcelain people can give us some light. Professor Orton just a few moments ago cited an instance of where manganese was increased from 17 pounds up to 23, or such a matter, and he also cited an instance of where it was increased from 14 up to 40, with substantially or what they presumed was the same furnace conditions, and still obtained green glass. In other words, the quantity of manganese put into that glass seemed to make no difference whatsoever with the color, it was green just the same. Now, there are instances of where only 6 pounds of manganese is used and good color is obtained. I know of an instance not far from New York City where they are using 36 pounds of manganese and substantially the same color is obtained as where 6 pounds is used. Professor Orton just told me of an instance of where they went from green over to violet with probably substantially no change in the furnace other than they reduced the amount of gas going into the furnace, increased the air going into it and produced an oxidizing condition. The fact that old glass makers will tell you that when you get a sharp fire, an oxidizing fire, you burn out your manganese and get low color effects, don't seem to substantiate that; you gentlemen who have made glass and have made colors, porcelains, tell us in what form does manganese exist to produce a white? When I say white, I mean transparent, or a pink or violet, and a green. All of these colors can be produced by manganese. In the glass business we do not know why it is.

Mr. Doe: Are you sure about that green?

Mr. Frink: Yes, sir, for this reason. I want to recite a little experiment first, so as to give you some idea on what I

base my statement. I have, in my laboratory, a pot furnace for covered pots. We made up a batch which contained the equivalent of 6 pounds of manganese to a thousand of sand; that is our basis usually in figuring our glass, which contains the equivalent of 350 pounds of soda ash and 120 pounds, I think it was, of burned lime, burned lime running about 92 percent $CaO + MgO$. We put that into the pot and made one melt, in which we kept a gas flame burning in the pot, just as smoky flame. We got green glass. We then took that same batch and put it into the pot and melted it with the pot simply standing open, and that glass was white. We then melted another batch in the same pot, introducing oxygen in the pot during the melt, through a hole in the cover in the stopper, so we maintained an oxygen atmosphere. We got it pink on the surface and violet underneath. Now, we took green glass and put it into a pot and melted it under oxygen, and we got it pink on the surface and shading down to a violet green, if you can imagine such a color. Those conditions seemed to me to prove that it is an oxidizing condition or a neutral condition that we require in the making of glass, in maintaining a high color. Furthermore, we have made some other experiments to determine if manganese would not produce a green, taking a batch which contains as small amount of iron as it is possible to find, and putting manganese in and getting a green color out of it. I want to learn in what condition manganese exists as related to these colors.

Mr. Binns: Unless I am mistaken, the manganous form of the oxide is colorless or pale; the manganic is a dark color. No doubt Mr. Frink's explanation is perfectly correct, but he does not account for the green, and I am assuming that the green color is due to the inability of the manganese to mask the iron. His last statement would seem to contradict, that, because he says there was practically no iron present, but I think every glass has more or less of a green tinge, if not neutralized. The reduction tends to develop the green color of the iron, but the condition of oxidation allows the manganese to develop the purple and thus mask the green. That is apparently what the condition is from the point of view merely of oxidation and

reduction. I stand subject to correction because I may be wrong.

Mr Frink: I do not think Prof. Binns needs any correction. However, I suggest a possible explanation of the manganese producing a green which is merely theory on my part, and that is, if you reduce manganese down so that a portion of it is in the manganous state, isn't it possible that such a condition of manganese would produce that green. We get the green and have made batches where the iron content was so very small that it seemed inconceivable that it would produce the green color we get. This green is a dark olive green.

Prof. Binns: Do you know absolutely that if the manganese had been left out, the glass would not have been green?

Mr. Frink: Yes, sir, when the manganese was left out, there was just a pale shade of bluish green bordering more upon the blue.

Mr. Shaw: My experience with glass batches has been that the amount of manganese necessary depends upon not only the burning condition, but the other materials in the batch. Where you are using 40 manganese as the maximum amount, if you put some more niter in, you can cut that 40 down to about 10. I have seen that done not only in glass tanks, but have done it repeatedly in small meltings. The color of manganese, so far as my experience tends to show is that it is always a question of oxidation and reduction. I do not question at all what Mr. Frink has shown here, but I have repeatedly shown that a little reduction will give you green, no matter how much manganese you have there. If you get reducing conditions, you get the green. I do not think you get it because of the manganese but because of the iron.

Mr. Orton: There are conditions where manganese does give a green. There is an old laboratory stunt we used to have to pull off in analytical work where we fused manganese oxide on a piece of platinum foil with sodium carbonate and nitre, and got a brilliant green melt invariably. Also blast furnaces have frequently given green slags when dealing with manganiferous ores. This is not always the case, however. I have seen

slags coming from furnaces producing 85 percent ferro-manganese, which were not green. I am simply attempting to show here that the green combination can result; what the conditions are, to produce it I would not attempt to define, but I have actually had slags come out green when working with low manganese ores (5 percent or under) and yet I have seen slags from manganese furnaces, with a very high manganese content in the furnaces and in the metal reduction, which were not green, though conditions are bound to be reducing in a blast furnace.

Mr Frink: I just want to say one more word, which perhaps will bring out something further. Prof. Orton's remark and Mr. Shaw's remark both corroborate what we have attempted to show in speaking of the use of niter. In the instance I cited, no niter had been used for sometime. They put in as high as 120 pounds of niter, trying to overcome that condition, which produced a lighter, brighter sea-green. In the experiment which I have spoken of, in which we took the glass and superimposed an atmosphere of oxygen over it, the green went from the olive to a bright green, and that, I believe, is in strict accordance with the explanation Prof. Orton has just offered. In the case of the blast furnace slag or the glass, the manganese has gone into combination after having been reduced, it is then put under oxidizing conditions, and there seems to be an intermediate degree of oxidation which brings us that green, color and then it is pretty difficult to get it out.

Mr. Colin: In regard to that manganese contention, if you take a sample of manganese dioxide and heat it to a high temperature in an electric furnace in a reducing atmosphere, you get that characteristic green, and although the general impression among glass men is that the green is due to iron, I can appreciate that conditions may easily be such that we would get a distinct green due to manganese. It is easy to show, in the electric furnace that the brown di-oxide of manganese will reduce to the green monoxide at high temperatures, and this color appears in the absence of any iron.

DISCUSSION CONTRIBUTED AFTER READING THE PAPER

Mr. Tillotson: I wish to call attention to the discussion by Dr. S. R. Scholes upon this subject (*J. Ind. Eng. Chem. 7,* 1037, 1915 and *J. Soc. Chem. Ind. 35,* 518, 1916). The work carried out by Dr. Scholes was prompted by observations which were in harmony with those stated by Mr. Frink, and an attempt was made to obtain information regarding the chemical condition of manganese in glass. The paper above referred to contains a rather full discussion of the subject, and it will be sufficient to mention here that all the evidence indicates that the pink color of manganese is due to a manganese compound — presumably a silicate — in which the manganese is in the *trivalent* condition. (Mn_2O_3)

It also seemed probable that the green manganese glass contained manganese in the hexavalent form, perhaps as sodium manganate. Sodium Manganate in the pure state is green and apparently is formed in some quantity during the fusion process, for a partially fused batch shows numerous green spots scattered through it. It was found possible too to make a glass which was colored green by manganese and which showed no pink color at any stage of the fusion. Inasmuch as sodium manganate can only be formed in the presence of strong bases, one would expect that the green color would appear most readily in very basic glass and less readily in glass containing a high percentage of silicate. This seems to be borne out in practice but is probably only one of the factors which may affect the color of the glass.

Mr. Poste: Although we have had no experience with glass manufacture there have come under our observation a few points which may have an interesting bearing on the foregoing discussion.

Some years ago in connection with experimental work on a new type of burner for a direct-fire enamel furnace, it was necessary to determine the proper air pressure on that burner to give an atmosphere in which the enamel would mature properly.

The particular experimental burner being used was so constructed that by varying the air pressure a large range of atmospheres could be obtained in the burning chamber. With

practically no forced draft there resulted a very reducing condition with but slight combustion taking place within the burning chamber itself. In the other extreme, with an air pressure of about 3½ inches of water, the combustion became very irregular due to the presence of a large excess of air. The entire field between these two extremes was covered quite carfully, and the point found at which the enamel would mature properly.

The particular enamel which was used in these experiments had been smelted in the ordinary type of coal-fired smelter. The batch contained approximately 4 percent of potassium nitrate based on the total weight of the raw materials. The approximate atmosphere existing in the smelter above the hearth was the following:

	Percent
Carbon dioxide	17
Oxygen	.7
Carbon monoxide	.3

In view of the fact that the theoretical amount of carbon dioxide in flue gas resulting from the combustion of bituminous coal, is slightly over 17 percent, it will be seen that the above represents practically no excess of air.

The enamel from this smelter was ground in the usual manner and applied to the ware. Under certain conditions of atmosphere in the burning furnace, instead of a pleasing glossy blue enamel, the color was inclined to be yellowish green, and the gloss was very inferior. The degree of this discoloration decreased as the amount of oxygen in the furnace increased until beyond a certain point the enamel appeared to be perfectly satisfactory. This range was covered several times, and the average gas analysis beyond which the enamel was always satisfactory gave the following results:

	Percent
Carbon dioxide	7.0
Oxygen	7.3

In other words it required the presence of about 7 percent of free oxygen in the burning chamber to properly mature this

enamel. As the amount of excess oxygen was diminished by lowering the air pressure, a gradual discoloration of the enamel took place. Increase in oxygen beyond this point did not improve the enamel.

A parallel feature is observed by enamelers who use muffle furnaces. When an ordinarily glossy enamel begins to lose its gloss and possibly color, the first thing the enameler looks for is a leaky muffle which means that reducing gases are getting through into the muffle from the combustion chamber surrounding it.

The above data would seem to have some weight in proving that at least under the conditions existing in the enamel furnace, the amount of oxygen present in contact with the enamel when it matures has a very direct bearing on the condition existing within the enamel in so far as the color-producing power of the cobalt is concerned. Apparently it is the highly oxidized material that gives the pleasing blue color while the reduced form which results from low oxygen gives a greenish yellow color or some other coloring effect exerts itself which is not covered up by the cobalt blue.

CHROME-TIN COLORS AT CONE 9

BY R. H. MINTON, METUCHEN, N. J.

The production of Chrome-tin colors in glazes at low temperatures has been quite thoroly covered by papers that have appeared in the Transactions, but little has been done with the problem of producing a color at high temperatures. The data presented in this paper are the result of rather desultory trials made from time to time, to produce a Cr-Sn stain that would develop a red when used in a slip under a transparent glaze at cone 9.

Three stains were selected as follows:

Stain No. 70		*Batch Weights*	
2.250	CaO	46.50	$CaCO_3$
.075	$PbCrO_4$	10.00	$PbCrO_4$
1.000	SiO_2	12.38	SiO_2
1.000	SnO_2	31.12	SnO_2

Stain No. 71		*Batch Weights*	
1.000	SnO_2	63.41	SnO_2
.8023	$CaCO_3$	34.14	$CaCO_3$
.0195	$K_2Cr_2O_7$	2.44	$K_2Cr_2O_7$

Stain No. 70 is the one selected by Ralcliffe and Walduck for their work in Vol. XVII (see p. 280), and stain No. 71 is one recommended by Carter (Vol. V, p. 243).

The third stain which we shall designate as No. 208, is one which can be purchased in the market, aand has been used by the writer in considerable amounts in making red terra cotta glazes at cone 5. Composition unknown.

Three slips were made including these stains as follows:

	Slip SA-1	Slip SA-2	Slip SA-3
20	Maine spar		
35	Flint		
38	China clay	Same using	Same using
5	Florida kaolin		
2	Whiting	Stain 70	Stain 208
20	Stain 71		

These slips were applied to a number of fire clay-grog tiles, about 9 in. by 6 in., ribbed to divide them into twelve equal divisions.

On each of these tiles were applied twelve different glazes to learn the type of glaze best suited to develop the red color with these stains.

The twelve glazes used have the following formulae:

GA-1 $\left.\begin{matrix} .23\ K_2O \\ .77\ CaO \end{matrix}\right\} .48\ Al_2O_3\ \ 3.90\ SiO_2$

See Mayer, Vol. I, p. 59.

GA-2 $\left.\begin{matrix} .30\ K_2O \\ .70\ CaO \end{matrix}\right\} .40\ Al_2O_3\ \ 3.80\ SiO_2$

See Montgomery and Kruson, Vol. XVI, p. 347.

GA-3 $\left.\begin{matrix} .20\ K_2O \\ .70\ CaO \\ .10\ MgO \end{matrix}\right\} .40\ Al_2O_3\ \ 3.50\ SiO_2$

See Howe, Vol. XVI, p. 492.

GA-4 $\left.\begin{matrix} .20\ \ KNaO \\ .525\ CaO \\ .175\ BaO \\ .100\ SnO_2 \end{matrix}\right\} .325\ Al_2O_3\ \ 2.75\ SiO_2$

See Hill, Vol. XVII, p. 387.

GA-5 .150 KNaO, .188 BaO, .562 CaO, .100 SnO_2 } .325 Al_2O_3 2.75 SiO_2

See Hill, Vol. XVII, p. 389.

GA-6 .095 KNaO, .620 CaO, .188 PbO, .097 BaO } .284 Al_2O_3 2.00 SiO_2

See Radcliffe and Walduck, Vol. XVII, p. 281.

GA-7 .1432 KNaO, .6760 CaO, .1807 BaO } .3137 Al_2O_3 2.4748 SiO_2 .2929 SnO_2

KNaO from stone and spar. CaO from $CaCO_3$

GA-8 .1854 KNaO, .5047 CaO, .3098 BaO } .4137 Al_2O_3 3.204 SiO_2 .3792 SnO_2

KNaO from stone and spar. CaO from $CaSO_4$

GA-9 .1024 KNaO, .7686 CaO, .1290 BaO } .2282 Al_2O_3 1.767 SiO_2 .2091 SnO_2

KNaO from stone and spar. CaO from CaF_2

GA-10 .1733 KNaO, .6079 CaO, .2187 BaO } .3867 Al_2O_3 2.994 SiO_2 .3544 SnO_2

KNaO from stone and spar. CaO from $CaCO_3$ and $CaSO_4$

GA-11 .1733 KNaO, .6079 CaO, .2187 BaO } .3867 Al_2O_3 2.994 SiO_2 .3544 SnO_2

Add 3 per cent $PbCrO_4$ CaO from $CaCO_3$ and $CaSO_4$

$$\text{GA-12}\quad \left.\begin{matrix}.1733\ KNaO\\ .6079\ CaO\\ .2187\ BaO\end{matrix}\right\} .3867\ Al_2O_3\quad 2.994\ SiO_2\quad .3544\ SnO_2$$

KNaO from par alone. CaO from $CaCO_3$ and $CaSO_4$

Glazes GA-7 to GA-12 were figured into formulae from batch weights of glazes containing stone which had been used at other times for other purposes. In reducing these to formulae the stone was considered to be:

$$\left.\begin{matrix}.65\ KNaO\\ .35\ CaO\end{matrix}\right\} 1.35\ Al_2O_3\quad 10.0\ SiO_2$$

Combining weight 830.

TABLE I — EQUIVALENTS

	GA-7	GA-8	GA-9	GA-10	GA-11	GA-12
Stone	.1543	.1998	.1102	.1868	.1868	.....
Spar	.0430	.0557	.0308	.0521	.0521	.1733
Whiting	.6221	.....	.....	.3929	.3929	.3929
Plaster Paris	.....	.4349	.....	.1397	.1397	.1397
Fluorspar	.....	.....	.7301	.....	.....	.....
Barium Carb.	.1807	.3098	.1290	.2187	.2187	.2187
China Clay	.0682	.0883	.0486	.0861	.0861	.2134
Flint	.5362	.6944	.3830	.6490	.6490	1.4666
Tin Oxide	.2929	.3792	.2091	.3544	.3544	.3544

All of the glazes in Table II were made up in batch weights in grams, and ground 10 hours in a small ball mill.

Burnings. A number of firings was arranged to note the influence of short and long burning, and also refirings.

Burn No. 1. Fired in small kiln 39 hours to cone 9 flat.

Burn No. 2. Made in large kiln firing 144 hours with cone 9 half turned.

Burn No. 3. Refiring in the large kiln after first firing in the trial kiln.

Burn No. 4. Fired again in the trial kiln after first firing in trial kiln, and then refiring in the large kiln.

TABLE II — GLAZE BATCH WEIGHTS

MATERIAL	GA-1	GA-2	GA-3	GA-4	GA-5	GA-6	GA-7	GA-8	GA-9	GA-10	GA-11	GA-12
Spar	128.1	167.1	111.4	111.4	83.5	52.9	24.1	31.0	17.1	29.0	29.0	96.5
Stone	.....	.....	.....	.....	....	.....	128.2	165.8	91.5	155.0	155.0	....
$CaCO_3$	77.0	70.0	70.0	52.5	56.2	62.0	62.2	.....	.....	39.3	39.3	39.3
$CaSO_4$	.....	.....	.....	.....	....	.....	.....	59.1	.....	19.0	19.0	19.0
CaF_2	.....	.....	.....	.....	....	.....	.....	.....	56.9	.....	.....	....
$BaCO_3$	.....	.....	.....	34.5	37.0	19.1	35.6	61.0	25.4	43.1	43.1	43.1
MgO	.....	.....	4.0	.....	....	.....	.....	.....	.....	.....	.....	....
China Clay	64.5	28.5	51.6	32.5	45.2	38.7	17.6	22.8	12.5	13.6	13.6	55.0
SiO_2	121.2	108.0	114.0	78.0	78.0	145.9	32.5	39.8	23.0	38.9	38.9	91.6
SnO_2	.....	.....	.....	14.9	14.9	.....	14.9	36.5	31.2	52.8	52.8	52.8
Pb_3O_4	.....	.....	.....	.....	....	41.7	.....	.....	.....	.....	.....	....
$PbCrO_4$	.....	.....	.....	.....	....	.....	.....	.....	.....	.....	11.7	....

Results from Burn No. 1

GA-1	over	SA-1	Very pale pink. Grayish.
		SA-2	Streaked pink. Purplish tint.
		SA-3	Almost white. Pink tint.
GA-2	over	SA-1	Slightly stronger pink than with GA-1
		SA-2	Slightly more pink than with GA-1.
		SA-3	Same as with GA-1.
GA-3	over	SA-1	Faint grayish pink.
		SA-2	Less pink than under GA-1.
		SA-3	Same as with GA-1.
GA-4	over	SA-1	Strong pink. Not uniform.
		SA-2	Strong rose pink. Uneven color.
		SA-2	Lighter pink than with GA-1.
GA-5	over	SA-1	Lighter pink than with GA-4. Not uniform.
		SA-2	Lighter rose than with GA-4. Not uniform.
		SA-3	Lighter pink than with GA-4. Not uniform.
GA-6	over	SA-1	Pinkish gray color. Glaze immature.
		SA-2	Stronger pinkish gray.
		SA-3	Pinkish white.
GA-7	over	SA-1	Strong pink. Stronger than with GA-4.
		SA-2	Good strong rose pink.
		SA-3	Good pink. Uniform color.
GA-8	over	SA-1	Good pink. But not quite as strong as with GA-7.
		SA-2	Good rose red. Lighter than with GA-7.
		SA-3	Good pink.

GA-9 over	SA-1	Light rose. Stronger than with GA-7.
	SA-2	Strong rose red. Better than with GA-7.
	SA-3	About like with GA-8.
GA-10 over	SA-1	Light pink. Nothing like with GA-1.
	SA-2	Much stronger pink than with GA-1.
	SA-3	About like with GA-1.
GA-11 over	SA-1	Stronger pink than with GA-10. Streaked.
	SA-2	Stronger pink than with GA-1. Purplish.
	SA-3	Stronger pink than with GA-2. Purplish.
GA-12 over	SA-1	Almost white. Glaze not matured.
	SA-2	Faint pink tint.
	SA-3	Creamy pink.

Summary: 1st, SA-2 is much the best slip.

2nd, GA-9 is much the best glaze for developing color.

Conclusions: 1st, To develop the pink color in the underslip the glaze must contain tin oxide.

2nd, Composition of the glaze seems to be of more importance than composition of the stain.

Result from Burn No. 2. The long firing in the large kiln has weakened the colors considerably, as was to be expected. As from the small kiln we find GA-9 to be the best glaze, and SA-2 the best slip.

Results from Burn No. 3. (Refiring.)

GA-1 over SA-2		Greenish gray tints. No signs of pink.
GA-2 over SA-2		Same.
GA-3 over SA-2		Same.
GA-4 over SA-2		Line of rose around edges.
GA-5 over SA-2		Faint line of pink around edges.
GA-6 over SA-2		No pink.
GA-7 over SA-2		Blotched pink and white.
GA-8 over SA-2		Same as with GA-7 but with less pink.

GA-9 over SA-2 Dark rose red. Small patches of white showing thru.
GA-10 over SA-2 Very pale pink tinted.
GA-11 over SA-2 Same.
GA-12 over SA-2 No pink.

Conclusions: Refire in large kiln has weakened the colors more than single fire in large kiln.

Results from Burn No. 4. (Refiring the second time.) Refiring in the small kiln, after having first refired in the large kiln, has had no effect upon the colors.

Conclusion: The results from the refirings indicate that in the long burning the colors are permanently lost, and cannot be restored by succeeding oxidizing fires.

PREPARATION OF STAINS

As a result of these trials stain No. 70 was selected as the base for further stains in which the sources of CaO and Cr_2O_3 would be varied.

These stains were as follows:

Stain No. 70. CaO from $CaCO_3$, and Cr_2O_3 from $PbCrO_4$.
Stain No. 72. CaO from $CaSO_4$, and Cr_2O_3 from $PbCrO_4$.
Stain No. 73. CaO from CaF_2, and Cr_2O_3 from $PbCrO_4$.
Stain No. 74. CaO from $CaCO_3$, and Cr_2O_3 from Cr_3O_4.
Stain No. 75. CaO from $CaCO_3$, and Cr_2O_3 from $K_2Cr_2O_7$.
Stain No. 76. CaO from $CaCO_3$, and Cr_3O_2 from K_2CrO_4.
Stain No. 77. CaO from $CaCO_3$, and Cr_2O_3 from $SrCrO_4$.
Stain No. 78. CaO from $CaCO_3$, and Cr_2O_3 from $BaCrO_4$.
Stain No. 79. CaO from $CaCO_3$, and Cr_2O_3 from Co_2CrO_4 $(OH_2).H_2O$.
Stain No. 80. CaO from $CaCO_3$, aand Cr_2O_3 from $ZnCrO_4$ $.7H_2O$.
Stain No. 81. CaO from CaF_2, and Cr_2O_3 from $K_2Cr_2O_7$.
Stain No. 82. CaO from CaF_2, and Cr_2O_3 from Cr_2O_3.

Preparation. Of each stain there were made 400 grams, which was first ground in a ball mill, dried, and calcined in flint lined crucibles to cone 9 in a large kiln.

TABLE III — STAINS — WEIGHTS IN PERCENTAGES

MATERIAL	NO. 70	NO. 72	NO. 73	NO. 74	NO. 75	NO. 76	NO. 77	NO. 78	NO. 79	NO. 80	NO. 81	NO. 82
SnO_2	31.12	26.44	34.42	33.45	32.67	32.17	32.08	31.57	31.34	32.08	36.66	37.63
SiO_2	12.38	10.65	13.86	13.47	13.15	12.96	12.92	12.71	12.62	12.92	14.76	15.16
$CaCO_3$	46.50	.....	.....	50.52	49.34	48.58	48.44	47.67	47.33	48.44	.....	.....
$CaSO_4$	.....	54.31	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
CaF_2	.....	.....	40.53	.....	.....	.....	.....	.....	.....	.....	43.17	44.33
$PbCrO_4$	10.00	8.60	11.19	.....	.....	.....	.....	.....	.....	.....	.....	.....
Cr_2O_3	.....	.....	.....	2.56	.....	.....	.....	.....	.....	.....	.....	2.88
$K_2Cr_2O_7$	.....	.....	.....	.....	4.84	.....	.....	.....	.....	.....	5.41	.....
K_2CrO_4	.....	.....	.....	.....	.....	6.29	.....	.....	.....	.....	.....	.....
$SrCrO_4$	.....	.....	.....	.....	.....	.....	6.56	.....	.....	.....	.....	.....
$BaCrO_4$	.....	.....	.....	.....	.....	.....	.....	8.05	.....	.....	.....	.....
Co_2CrO_4 $(OH)_2$ H_2O	.....	.....	.....	.....	.....	.....	.....	.....	8.71	.....	.....	.....
$ZnCrO_4$ $7H_2O$	.....	.....	.....	.....	.....	.....	.....	.....	.....	6.56	.....	.....

Condition of Calcined Stains.

Stain No. 70. Pink. Soft.
Stain No. 72. Purplish red.
Stain No. 73. Lilac.
Stain No. 74. Very dark red. Soft. Flint lining stained green.
Stain No. 75. Dark red. Soft. Dark green crystals of chrome on lining.
Stain No. 76. Dark red. Soft. Dark green on flint lining.
Stain No. 77. Dark red. Soft. No green stain on flint lining.
Stain No. 78. Dark red. Soft. Same as for No. 77.
Stain No. 79. Lilac. Soft. Dark blue on flint lining of crucible, and bright pink and blue below stain.
Stain No. 80. Red. Soft. Bright red on flint below line of stain.
Stain No. 81. Lilac. Sintered hard. Stained dark green on lining.
Stain No. 82. Lilac. Sintered hard. No green stain.

Stained slips. A series of slips was made, beginning with SA-4, which is the same as SA-2 with 20 percent of stain No. 70, and continuing with SA-5 to SA-15, with stains Nos. 72 to 82 respectively. Of each slip a batch of 200 grams was made and ground six hours in a small ball mill. These slips were applied to the fire clay-grog tiles, which were marked into divisions with ribs.

Glazes. To learn the comparative colors produced from these several stained slips, three glazes GA-25, GA-26 and GA-27, were made and applied over each set of slipped tiles.

GA-25

$$\left.\begin{matrix}.2078\ KNaO\\ .6976\ CaO\\ .0946\ BaO\end{matrix}\right\} .3974\ Al_2O_3 \left\{\begin{matrix}2.9225\ SiO_2\\ .2000\ SnO_2\end{matrix}\right.$$

GA-26

$$\left.\begin{matrix}.25\ K_2O\\ .65\ CaO\\ .10\ BaO\end{matrix}\right\} .35\ Al_2O_3 \left\{\begin{matrix}3.00\ SiO_2\\ .20\ SnO_2\end{matrix}\right.$$

GA-27

$$\left.\begin{matrix}.1024\ KNaO\\ .7686\ CaO\\ .1290\ BaO\end{matrix}\right\} .2282\ Al_2O_3 \left\{\begin{matrix}1.7670\ SiO_2\\ .2091\ SnO_2\end{matrix}\right.$$

TABLE IV — EQUIVALENTS AND BATCH WEIGHTS

	GA-25		GA-26		GA-27	
Stone	.1659	137.70	.....	.....	.1102	91.50
Spar	.1000	55.70	.25	139.25	.0521	17.10
Whiting	.5396	53.96	.65	65.00	.....	.....
Fluorspar	.....	.....	.....	.....	.7301	56.90
Barium Carb.	.0946	18.63	.10	19.70	.1290	25.40
China Clay	.0735	18.96	.10	25.80	.0486	12.50
Flint	.5165	39.99	1.30	78.00	.3830	23.00
Tin Oxide	.2000	29.80	.20	29.80	.2091	31.20

Burn No. 5. These trials were burned in the trial kiln to cone 9, firing for 40 hours.

Results from Burn No. 5. Glazes. GA-25 is a semi-glossy enamel. Seems too opaque to develop the colors well. SA-12 is blue, and all others faded pinks.

GA-26 is a glossy enamel and develops the colors much better than GA-25.

GA-27 is not well matured, but brings out the colors about as under GA-26. Edges of SA-10 and SA-11 much darker color than under GA-26.

Colors developed by GA-26.

SA-4	(stain No. 70)	Light rose pink.
SA-5	(stain No. 72)	Not quite so strong as SA-4.
SA-6	(stain No. 73)	Lighter than SA-5.
SA-7	(stain No. 74)	Darker rose than SA-4.
SA-8	(stain No. 75)	About the same as SA-5.
SA-9	(stain No. 76)	Like SA-8.

SA-10 (stain No. 77) Dark rose.
SA-11 (stain No. 78) Same as SA-10.
SA-12 (stain No. 79) Blue.
SA-13 (stain No. 80) Pink. Lighter than SA-6.
SA-14 (stain No. 81) About the same as SA-6.
SA-15 (stain No. 82) Dark rose. About the same as SA-7.

Summary: $CaCO_3$ is slightly better than CaSO4 in the stain.

CaF_2 is not so good as $CaCO_3$ or $CaSO_4$ with $PbCrO_4$.
Cr_2O_3 is better than $PbCrO_4$ with CaF_2.
Cr_2O_3 makes darker shade than $K_2Cr_2O_7$ or K_2CrO_4.
$SrCrO_4$ and $BaCrO_4$ produce darker colors than Cr_2O_3.
$ZnCrO_4$ not so strong as $SrCrO_4$ or $BaCrO_4$.
CaF_2 not so strong as $CaCO_3$ with $K_2Cr_2O_7$ but about the same with Cr_2O_3.
$Co_2CrO_4(OH_2).H_2O$ produces blue.

Conclusions: 1st, $SrCrO_4$ and $BaCrO_4$ produce stronger colors than any other source of Cr_2O_3 tried. $BaCrO_4$ seems slightly the best.

2nd. Cr_2O_3 seems to be the next best source of Cr_2O_3.
3rd. $CaSO_4$ is not so good as either $CaCO_3$ or CaF_2.
4th. $ZnCrO_4$ produces a strong color.
5th. The source of the Cr_2O_3 has a marekd effect upon the color and strength developed.

GLAZE SERIES VARYING SOURCES OF CaO AND AMOUNTS OF SnO_2

Six glazes, GA-30 to Ga-35, were made. In the first three the sources of the CaO were $CaCO_3$, $CaSO_4$ and CaF_2, while each has .10 SnO_2. Of the last three GA-33 has no SnO_2 while GA-34 has .20 eq. and GA-35 has .30 equivalents.

TABLE V — GLAZE EQUIVALENTS

GLAZE	RO				R_2O_3	RO_2	
	KNaO	CaO	BaO	SnO_2	Al_2O_3	SiO_2	SnO_2
GA-30	.200	.625	.075	.100	.300	2.50	....
GA-31	.200	.625	.075	.100	.300	2.50	....
GA-32	.200	.625	.075	.100	.300	2.50	....
GA-33	.200	.725	.075	....	.300	2.50	....
GA-34	.200	.625	.075	.100	.300	2.50	.100
GA-35	.200	.625	.075	.100	.300	2.50	.200

TABLE VI — BATCH WEIGHTS

MATERIAL	GA-30	GA-31	GA-32	GA-33	GA-34	GA-35
Spar	111.4	111.4	111.4	111.4	111.4	111.4
$CaCO_3$	62.5	....	....	72.5	62.5	62.5
$CaSO_4$	....	85.0	....	....	....	....
CaF_2	....	....	48.7	....	....	....
$BaCO_3$	14.8	14.8	14.8	14.8	14.8	14.8
SnO_2	14.9	14.9	14.9	....	14.9	14.9
China Clay	25.8	25.8	25.8	25.8	25.8	25.8
Flint	66.0	66.0	66.0	66.0	66.0	66.0
SnO_2	....	....	....	....	14.9	29.8

Burn No. 6. This series of glazes GA-30 to GA-35 was applied over stains SA-14 and SA-15, and burned in the trial kiln 40 hours to cone 9.

Results from Burn No. 6. (Trial Kiln.)

GA-30 over { SA-14 Strong pink color. / SA-15 Dark rose red.

GA-31 over { SA-14 Pink streaked with white. / SA-15 Rose streaked with white.

GA-32 over { SA-14 Same as with GA-30. / SA-15 About like GA-30, but with white spots.

GA-33 over { SA-14 Grayish with faint pink tint. / SA-15 Dark greenish gray, some pink tint.

GA-34 over { SA-14 Same as with GA-30.
SA-15 Same as with GA-30.

GA-35 over { SA-14 Lighter pink than with GA-30.
SA-15 Lighter rose than with GA-30.

Conclusions: 1st. $CaCO_3$ and CaF_2 equally good and either better than $CaSO_4$.

2nd. Glaze must contain SnO_2 to develop the color.

3rd. .10 to .20 eq. of SnO_2 best, but .30 eq. too much.

4th. Slip SA-15 with stain No. 82 is much stronger than SA-14 with stain No. 81.

5th. Composition of the glaze seems of more importance than the composition of the stain.

Results from Burn No. 7. (Large Kiln.) The results from firing this series in the large kiln are about the same as from trial kiln, except that colors are not so good, and show signs of burning out on the high spots, or ribs of the titles. GA-32 seems to stand up the best, while GA-35 is almost white.

FURTHER STAIN TRIALS

Since $BaCrO_4$ as the source of Cr_2O_3 in stain No. 78 had given such a strong color, it was determined to make another stain using it in connection with CaF_2. At the same time three other stains of another formula were made to make further comparison with stain composition.

Stain No. 84 has the same formula as stain No. 70. Stains Nos. 85, 8 6and 87 have the formula: 1.000 SnO_2, .8582 CaO and .0212 $K_2Cr_2O_7$. The sources of materials and the weights of these stains are shown in Table VII.

TABLE VII — STAINS

MATERIALS	NO. 84	NO. 85	NO. 86	NO. 87
CaF_2	41.7	....	30.1	29.6
$CaCO_3$	....	35.6	....	....
$BaCrO_4$	8.9	....	....	4.8
$K_2Cr_2O_7$	....	2.6	2.8	....
SiO_2	14.2	....	....	....
SnO_2	25.2	61.8	67.1	65.6

These stains were made up in amounts of 400 grams each by grinding in a ball mill, and calcined in a long fire to cone 9.

Appearance of Stains: No. 84, Lilac. Fused hard. Interior has not developed the color at all.

No. 85 — Dark red. Very soft. Very dark green chrome crystals above stain on the flint lining of crucible.

No. 86 — Very dull purplish red. Sintered quite hard.

No. 87 — Same as No. 86.

Series of Colored Glazes.

To investigate the action of the various stains when introduced directly into a glaze, this series GC-1 to GC-12 was made using the same formula as for GA-30. In each glaze there was incorporated 10 percent of stains Nos. 70, 73, 75, 77, 78, 81, 82, 84, 85, 85 washed, 86 and 87 respectively.

Each glaze was made up in grams to the amount of the batch weight, and applied to the trial tiles as before, and fired in the small and large kilns, to cone 9.

Results from Burn No. 8. (Trial Kiln.)

GC-1	(Stain No. 70)	Rose. Opaque enamel with some gloss.
GC-2	(Stain No. 73)	Very slightly darker rose than GC-1.
GC-3	(Stain No. 75)	Lighter rose than GC-1 and GC-2
GC-4	(Stain No. 77)	Dark red.
GC-5	(Stain No. 78)	Dark red. Trifle lighter than GC-4
GC-6	(Stain No. 81)	Pink.
GC-7	(Stain No. 82)	Red. Lighter than GC-5.
GC-8	(Stain No. 84)	Dark red. Darker than GC-4.
GC-9	(Stain No. 85)	Pink. About like GC-6.
GC-10	(Stain No. 85 washed)	Pink. About like GC-9.
GC-11	(Stain No. 86)	Lighter pink than GC-10.
GC-12	(Stain No. 87)	About like GC-11.

Summary. $PbCrO_4$ regardless of source of CaO does not produce dark reds. Stains Nos. 70, 72 and 73.

$SrCrO_4$ and $BaCrO_4$ with $CaCO_3$ produce very dark reds, much darker than $K_2Cr_2O_7$ with $CaCO_3$ or CaF_2. Stains Nos. 77 and 78.

Cr_2O_3 produces much darker color than $K_2Cr_2O_7$. Stains Nos. 80 and 81.

$BaCrO_4$ with CaF_2 produces much darker red than either $K_2Cr_2O_7$ or Cr_2O_3.

Conclusions. 1st — $SrCrO_4$ and $BaCrO_4$ are better sources of Cr_2O_3 than $PbCrO_4$, $K_2Cr_2O_7$, K_2CrO_4 or Cr_2O_3.

2nd. — Cr_2O_3 is much better than $PbCrO_4$, $K_2Cr_2O_7$, or K_2CrO_4.

3rd. — CaF_2 produces stronger colors than $CaCO_3$.

4th. — Stain of type of No. 70 is stronger than type of No. 85.

CHROME-TIN COLORS AT CONE 02

While the preceding trials were being run it was thought that it might be interesting to try these stains in a fritted glaze to fire at cone 02. Accordingly there was selected a glaze of the type used by Purdy in all his Cr-Sn experiments. This glaze has the following formula: —

Glaze:

$$\left.\begin{matrix} .22PbO \\ .59\ CaO \\ .19\ KNaO \end{matrix}\right\} .16\ Al_2O_3 \left\{\begin{matrix} 2.10\ SiO_2 \\ .475\ B_2O_3 \end{matrix}\right.$$

Frit:

$$\left.\begin{matrix} .09\ K_2O \\ .10\ Ka_2O \\ .59\ CaO \end{matrix}\right\} .12\ Al_2O_3 \left\{\begin{matrix} 1.75\ SiO_2 \\ .475\ B_2O_3 \end{matrix}\right.$$

Batch Weights:

Glaze		Frit	
56.76	White lead	50.13	Spar
10.32	China clay	38.20	Borax
20.20	Flint	7.74	China clay
198.19	Frit	69.00	Flint
		34.10	Boric acid.

Glazes GB-1 to GB-12 to which were added, respectively, 10 percent of stains No. 70 and Nos. 72 to 82, were made by grind-

ing in a ball mill for ten hours. The glazes were then applied to tiles and fired in a small kiln for 30 hours to cone 02.

Results from Burn No. 9.

GB-1 (stain No. 70) Reddish brown. Lilac tint. Milky.
GB-2 (stain No. 72) Almost the same as GB-1.
GB-3 (stain No 73) Slightly lighter shade than GB-1 and GB-2.
GB-4 (stain No. 74) Stronger brown tint than GB-1 and GB-2.
GB-5 (stain No. 75) Brownish red. Milky.
GB-6 (stain No. 76) Same as GB-5.
GB-7 (stain No. 77) Stronger brown than GB-4. Milky.
GB-8 (stain No. 78) Rich, dark brown red. Clear.
GB-9 (stain No. 79) Dark blue. Milky.
GB-10 (stain No. 80) Nearly the same as GB-2. Not quite so milky.
GB-11 (stain No. 81) Good red. Clear. Not milky.
GB-12 (stain No. 82) Dark brownish red. More reddish than GB-8. Clear.

Summary. $PbCrO_4$ causes milkiness with every source of CaO.

$CaCO_3$ produces milkiness with every source of Cr_2O_3 except $BaCrO_4$.

CaF_2 with Cr_2O_3 gives entirely different color than with $PbCrO_4$ or $K_2Cr_2O_7$.

CaF_2 with $K_2Cr_2O_7$ does not show milkiness and gives the only real red.

Conclusions. 1st. — BaCrO develops the strongest shades, with brownish tints.

2nd. — CaF_2 seems to be the best source of CaO.

3rd. — Both the source of the CaO and the source of the Cr_2O_3 strongly influence the color and shade developed by the stain in the glaze.

4th. — $K_2Cr_2O_7$ is the best source of Cr_2O_3 for clear red.

5th. — Milkiness seems to be the result of incomplete reaction between the Cr_2O_3 and the CaO, depending upon the sources of each, and probably too low CaO.

EFFECT OF WASHING THE STAINS

In order to learn whether washing the strains has any effect upon the color produced in a glaze, all stains Nos. 70 to 82 were thoroughly washed until clear. Stains Nos. 70, 72, 74, 75, 76, 77 and 78 required considerable washing to free from excess chrome salts. Stains Nos. 73, 79, 80, 81 and 82 showed clear from the first washing.

A series of glazes GB-20 to GB-31, based upon formula of GB-1, was made with, respectively, stains Nos. 70, 75, 76, 80, 78, 81 and 82 washed; stains Nos. 84 and 85 not washed; stain No. 85 washed; and stains Nos. 86 and 87 not washed.

Results from Burn No. 10. (Trial Kiln-Cone 02.)

GB-20 (stain No. 70) Slightly brownish red. Little white scum.

GB-21 (stain No. 75) Less brownish red. Very little white scum.

GB-22 (stain No. 76) Pink. Little scum. Much better than with GB-6.

GB-23 (stain No. 80) Same as GB-20. Much better than with unwashed stain.

GB-24 (stain No. 78) Brown. Absolutely unlike GB-8 (unwashed stain).

GB-25 (stain No. 81) Pink. Not nearly as good as when unwashed.

CB-26 (stain No. 82) Brown. Not nearly so rich as unwashed.

GB-27 (stain No. 84 not washed) Very pale brownish pink tint. This is not true color, as stain was not uniformly developed.

GB-28 (stain No. 85 not washed) Very good red. Some scum where heavy.

GB-29 (stain No. 85 washed) Seems slightly improved over GB-28.

GB-30 (stain No. 86) Slightly brownish pink. Some scum where heavy.

GB-31 (stain No. 87) Pink. Some scum where heavy.

Summary. Stains Nos. 70, 75, 76 and 80 are greatly improved by washing. Most of the white scum has disappeared.

Stains Nos. 78 and 82 have lost their rich colors by washing. Colors very much weaker.

Stain No. 81 has changed from red to pink thru washing.

Conclusions. 1st — Stains of the types of 70 and 85 may both produce good colors at this temperature.

2nd — Unwashed stains are considerably the best, for strong colors. Washing greatly influences the shade.

3rd — Source of the Cr_2O_3 has marked influence upon the final color developed in the glaze.

DISCUSSION

Mr. Hunt: I would like to say, in respect to washed chrome-tin pinks, that I did some work myself, running some unwashed glazes alongside the washed and I think you have got to consider them very closely.

Mr. Shaw: I would like to ask Mr. Minton if he ever did anything in the way of making a stain, putting the colors right in the glaze, fitting the glaze?

Mr. Minton: Yes, ten years ago I made a chrome-tin pink color in a tile factory without ever fritting the glaze, although I will say it was not quite as good as if it had been fritted, although it is quite possible that, by making the formula according to the original fritted formula, putting the materials in raw and putting them in the proportion of oxide of chrome, you will get a fine red color. It is usually a little light around the edges, however, on tile and that is the principal objection to it.

NOTE ON THE PRODUCTION OF SPECIAL REFRACTORIES — MARQUARDT PORCELAIN AND MAGNESIUM ALUMINATE[1]

BY F. H. RIDDLE

1. MARQUARDT PORCELAIN

Marquardt poreclain is used in the production of pyrometer tubes and similar ware. The chief source of production, up to about a year ago, was Germany. The Bureau of Standards has done considerable experimental work with a view of reproducing this ware, and described some of the work in Vol. XVIII.[2] The present work is a continuation of what has already been done, and the processes have been brought to a point where the manufacturing is being done on a commercial basis.

The body mixture was based on the analysis of a sand blasted Marquardt tube, and was as follows[3]:

Body	*percent*
Grog No. 1	45.7
Grog No. 2	7.3
N. C. kaolin	17.0
Florida kaolin	5.0
Tenn. ball clay No. 5	15.0
English china clay	10.0
	100.0

Grog No. 1	*percent*
Calcined Al_2O_3	70.0
N. C. kaolin	22.0
Potash spar	8.0
	100.0

Grog No. 2	*percent*
Potash spar	64.0
Calcined Al_2O_3	36.0
	100.0

[1] By permission of the Director of the U. S. Bureau of Standards.

[2] W. L. Howat on Marquardt Porcelain, *Vol. XVIII*, 1916.

[3] Since this paper has been presented we have made alterations in the composition of the Marquardt porcelain body. These alterations are only necessary where the tubes are to be used at very high temperatures. In that case Grog No. 2 should be omitted and 53 percent of Grog No. 1 used in place of 45.7 percent.

The labor of preparing the grogs can also be lessened a great deal by grinding the raw grogs dry, sieving through a 20 mesh screen and filling the saggers full of the loose materials. The calcining will shrink the material enough so as to permit the heat to penetrate all parts, and the grinding after calcination is much more easily accomplished than where it is previously made up into balls.

Preparation of the Grog and Body. Each grog mixture was ground dry in a ball mill to insure thorough mixing of the materials. It was then tempered with water to the consistency of a very thick paste and molded by hand into balls about 1¼ in. in diameter. These were thoroughly dried and calcined in saggers to cone 19 to 20. No. 2 grog which is high in feldspar, vitrified sufficiently for the balls to flatten out of shape. No. 1 grog has the shrinkage well taken out of it, but does not vitrify. The calcined grogs were crushed to 12 mesh, and ground dry in pebble mills until fine enough to pass through the 120 mesh lawn.

The body was blunged, put through a 120 mesh lawn and filter-pressed. For use in making power-pressed tubes a solution of gum tragacanth was added to the body, and the mass thoroughly pugged. The water content of the mixture which gave the best results, in our case, was 28.8 percent, in terms of the dry weight of the body. The amount of gum added was 0.16 percent, in terms of the dry weight. The dry gum was put in solution in boiling water before adding it to the clay. The pugging was done in a pill mixer. This has proved very satisfactory on account of its continuous repugging. This pugging process was carried on about 20 minutes.

It would be difficult to use as stiff a mixture in a potters pug mill, and it would be necessary to pass the material through the mill several times before an equivalent amount of tempering could be accomplished.

For casting purposes the slip was filtered and sufficient water added to make 60 percent of the dry weight. This necessitated determining the moisture factor. After thoroughly blunging, sufficient salt was added to thin the slip down so that 200 cc. would run through the viscosimeter in two minutes. The viscosimeter used was a brass efflux tube as described by Bleininger.[4] With the body in question, the following procedure was used. To make 20 tubes 550 by 15 by 10 mm. 4500 gr. of filter plate clay containing 25 percent water was blunged with 625 cc. of water. To this 65 cc. of a $3^1/_3$ percent solution

[4] *Technologic Paper No. 51* of the Bureau of Standards.

of Na_2SiO_3 and 22½ cc. of a 10 percent solution of Na_2CO_3 was added.

Two methods were employed, one consisting in pressing the smaller tubes on a press and the other in casting the larger tubes.

Manufacture of Tubes by Pressing. It is possible to make all sizes of tubes from 2 mm. o. d. by 0.6 mm. i. d.[5] up to practically any size desired, by this method. We have not made tubes more than 15 mm. o. d. The machine used is a miniature hydraulic press built very similar to a sewer pipe press. The water cylinder is 8 in.. in diameter, the clay cylinder is 3½ in. in diameter and the stroke is 10 in. All dies are made of brass and accurately finished. The water pressure used to operate the press is 80 pounds to the sq. in. This machine works very well and makes very dense tubes. The troubles encountered are the ordinary ones that would be expected with a machine of this type, *viz.*, necessity of maintaining absolute water content and uniform pugging to prevent clay running faster on one side of the die than on the other. Ring cracks also form at the point of the die when the column is held so as to throw back the plunger to recharge the mud cylinder. The longer the stroke, consequently, the fewer the ring cracks would be formed and the greater would be the production. Hence a stroke of 24 in. would be preferable. If the press is vertical, the length of the tube is limited by the tensile strength of the clay, but this will permit the making of at least three-foot tubes. If the press is inclined or horizontal, it is necessary to use a hand controlled off bearing belt. We have found that the press is satisfactory for all the sizes of tubes we require, and that its capacity is sufficiently high. At present we are casting all sizes used, whose bores are sufficiently large to permit the use of that process; *i. e.*, 4 mm. o. d. and over. The tubes can be cast much truer, do not have to have the closed ends put on by hand, and can be handled much more easily, particularly in the long sizes. The collars must be stuck on by hand in either case. It is possible to design a press that would perform both of these operations, but there would be nothing gained for the

[5] Outside diameter = o. d.; inside diameter = i. d.

press over the casting. It is possible to run a straight tube out of the press, suspend it vertically to dry and yet have it dry crooked. This occurs when the core is slightly off center, and yet near enough so the soft plastic clay will be held straight until the tube begins to dry and shrink.

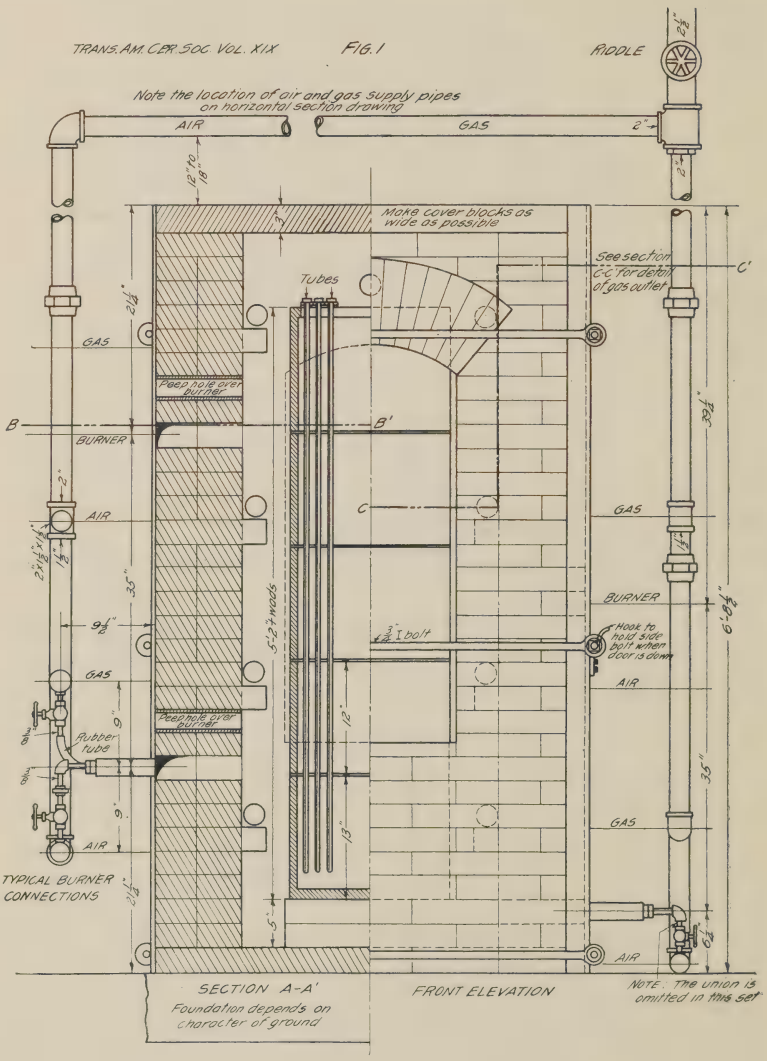
Manufacture of Tubes by Casting. The speed and trueness of this work, of course, depends primarily upon the plaster molds. For long small diameter molds for tubes closed on one end, the mold should be cast around a cold drawn steel rod, on account of its trueness. The end of the rod should be rounded off as desired, and a hole about $^1/_{16}$ in. in diameter drilled in the center at this end, probably $^3/_8$ in. deep. The other end of the rod should be mounted in the center of a plaster block about 6 in. high and 4 in. in diameter. The molds are cast by placing the rod vertically on the mounting, and wrapping a "coddle" of roofing paper, or similar flexible material, around the mounting and maintaining this measure up to a height of a few inches above the top of the rod. Then run a $^1/_{16}$ in. pin about 3 in. long down in the small hole in the top end of the rod. Prepare the plaster and fill the "coddle" so that the pin sticks out of the plaster about one-half inch. This $^1/_{16}$ in. hole through the bottom of the mold, made by drawing the pin out, serves as an air inlet, making it possible to pull the rod out of the mold, and also serves the same purpose in pulling out the cast tubes. It would be impossible to cast thin tubes without this air inlet, particularly the 1200 mm. tubes of about 18 mm. o. d., as the slip, when poured out, would form a partial vacuum, and the tubes would collapse. With one steel block tube and "coddle" case, two men can cast sixty inch tube molds at the rate of one every half hour. Smaller molds can be cast somewhat faster. The speed of casting ware depends upon the number of molds, working conditions, etc. Under normal conditions, we have been able to cast and take care of twenty 550 by 15 to 10 mm. tubes an hour, including sticking heads on, etc. This rate could be increased a good deal by using two men, having enough molds and proper supply of tubes, etc.

The following table shows the time the slip was left in the molds before being turned out:

DIMENSIONS OF TUBE		TIME OF HOLDING	TIME BEFORE TUBE CAN BE DRAWN FROM MOULD
LENGTH IN MM.	I. D. BY O. D.		
1200	18 — 11	1 min. 10 sec.	24 hours
500	5 — 3	30 sec.	24 hours
550	15 — 10	2 min.	24 hours
250	36 — 30	4 min.	24 hours

The one special requirement in casting is that the air inlet hole in the mold must be used properly. A piece of wire, bailing wire, is run into the small hole in the bottom of the mold until it projects into the mold proper about ½ in. It is bent over on the outside of the mold and cut off about 1 in. from center. It is held in place with soft clay. After the slip is poured into the mold and it is time to empty it out, the pin must be taken out while the mold is being turned. If the pin is taken out too soon the slip will run down in and plug the hole, and if the pin is left in after slip begins to run out at the other end, the tube will collapse.

Considerable care must be used in drying the tubes, and proper pallets are necessary. Plate glass is ideal for the purpose. Where wood is used there should be a stiff reinforcement running lengthwise of the pallet underneath, as well as cleats crossways. The boards should be of the same length as the green tubes and have a stop block running the entire length, along one edge. The first tube is placed against this, and the next one rolled close to the first, but with the head on the opposite end of the pallet, etc. This method permits the necessary clearance for the heads and has each tube held on both sides for its entire length. (See Fig. 3.) If the pallets are longer than the tubes the head end of each tube will be without a brace on either side, for a distance equal to the difference between the length of the tubes and pallet. The last tube from the stop block is held in place by a ½ in. square steel rod. Twenty-four hours is sufficient for drying.


TRANS. AM. CER. SOC. VOL. XIX
FIG. 1
RIDDLE
Note the location of air and gas supply pipes on horizontal section drawing
AIR
GAS
2"
12" to 18"
Make cover blocks as wide as possible
See section C-C for detail of gas outlet
C'
Tubes
GAS
Peep hole over burner
B
B'
BURNER
2"
AIR
C
GAS
BURNER
Hook to hold side bolt when door is down
3/4" I bolt
5'-2" wide
AIR
GAS
Peep hole over burner
Rubber tube
AIR
GAS
AIR
TYPICAL BURNER CONNECTIONS
SECTION A-A'
Foundation depends on character of ground
FRONT ELEVATION
NOTE: The union is omitted in this set

Burning. The tubes should be set in special saggers and hung from the heads by use of universal swinging rings which are illustrated in Figure 3. A satisfactory mixture for saggers is

	percent
8-30 flint clay grog	55
Georgia kaolin	35
English ball clay	10

Cone 1, or above, is sufficient heat for the biscuit burn. The glost burn depends upon the melting point of the glaze, but should not be below cone 16. The tubes are set in the same way in the glost burn as they are in the biscuit burn. The glazing can probably be done by dipping, if a proper horizontal trough is used, but we have sprayed all tubes. This requires considerable time, but insures uniform application and absence from checking, which sometimes occurs in dipping. Too much care cannot be taken in hanging the tubes in burning. If they do not swing freely they will burn crooked. It is also essential that they be heated evenly on all sides as they will draw to the hot side and burn crooked.

We have burned several tubes in single fire; and here, of course, spraying is necessary. The best type of glaze to use, as far as usefulness of the tube in practice at high temperatures is concerned, is a high whiting mat glaze of the formula:

$CaO.Al_2O_3.4SiO_2$, maturing at cone 17.

Several other glazes can be used, but they become sticky at 1300° C. and are not so good for that reason. Two of such glazes are represented by the formulae:

(1). $1.0CaO,\ 1.0Al_2O_3,\ 10.0SiO_2$.

(2). $\left.\begin{matrix}.15K_2O\\ .20MgO\\ .65CaO\end{matrix}\right\}\ 1.0Al_2O_3,\ 10.0\ SiO_2$.

Both are bright glazes at cone 17.

All these glazes are absorbed into the body when overfired, and the tubes have the appearance of biscuit tubes. If

broken the cross section shows, however, that the glaze has been absorbed. There is no reason why these tubes should not be as good as the ones where the glaze is still on the surface, and they will not stick to anything at high heats. The best tubes appear to be those which are burned rapidly in the glost fire. A small gas-fired kiln holding three or four dozen 22-in. tubes can be burned without danger, in five or six hours.

It is essential that the heat be uniform in the kiln to prevent drawing of the tubes, due to more shrinkage on one side than on the other. This trouble is best overcome by having saggers about 4 in. wide and 12 in. to 14 in. long and suspending only one row of tubes in them. If the saggers are heated evenly on both sides, the tubes will be straight. If two rows of tubes were put in one sagger, each row would be crooked, the bottoms turning out toward the wall. A kiln suitable for burning 1,500 mm. tubes is illustrated in Figures 1 and 2.

Physical Properties of the Tubes. Several comparative tests of German and Bureau tubes have been made, and they are very similar in character. The glaze on both tubes is absorbed at about the same temperature; i. e., cone 20 to 22. Suspension tests were made by supporting 8-in. sections of tubes horizontally between two supports about 7 in. apart. The tubes sagged about $\frac{1}{8}$ in. at cone 22. The German tubes sagged slightly less than the others, but were of a little heavier construction. All tubes will stand very severe changes of temperature. We have put cold tubes 1200 mm. into a kiln at a temperature of 1500° C. without apparent weakening. This has been repeated several times. The time taken in inserting the tube was about $\frac{1}{4}$ minute.

II. MAGNESIUM ALUMINATE (SPINEL)

Considerable work has been done in the last few years on the fusion points of various refractory oxides and mixtures of these, including a study of their eutectics and the stability of the various compounds formed.

Kanolt shows the melting points of several oxides and platinum to be as follows:

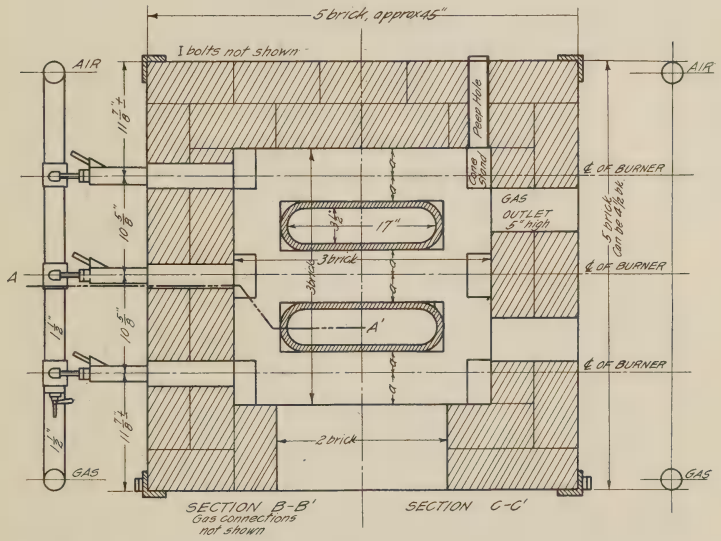
	°C
MgO	2800
CaO	2572
Al_2O_3	2050
Cr_2O_3	1990
Platinum	1755

TRANS. AM. CER. SOC. VOL. XIX FIG. 2 RIDDLE

UP-DRAFT TUBE KILN
CAPACITY 18 60 IN. TUBES
DESIGNED FOR FLETCHER BURNERS USING NATURAL GAS, AND AIR AT 35 POUNDS.

Note:- If kiln is made 4½ brick deep instead of 5, make other measurements to correspond.

There are 4 Gas Outlets each 4½" x 5". For location see SECTION C-C'. Damper these as required with loose brick



All the investigators who have studied lime, alumina, and magnesia alumina mixtures agree that the most stable compound in contact with the melt, is magnesium aluminate ($MgO.Al_2O_3$); *i. e.*, MgO — 28.4 percent, Al_2O_3 — 71.6 percent. Rankin and Merwin show its fusion temperature to be 2135° C ± 20°. This compound is crystalline and appears usually in the form of

octahedra. It is strictly isotropic unless the alumina is greatly in excess. Its refractive index, $n = 1.718 \pm .002$.

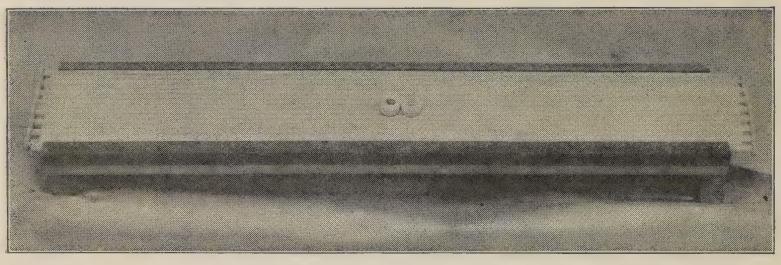


FIG. 3.

Two allotropic forms of Al_2O_3 are known. The common form called alpha, is the same as the mineral corundum. The magnesia alumina study (by Rankin and Merwin) called attention to a second form known as beta. Its relation to the alpha form is not yet definitely known. Analysis by H. S. Washington shows it to be pure Al_2O_3 and not Al_3O_4, as it was thought to be. The fusion temperature of both forms is 2050° C., and the eutectic mixtures with MgO. Al_2O_3 are both 1925° C. Among other binary compounds are:

	Fusion Point.
Al_2SiO_3	1816° C.
$5CaO.3Al_2O_3$	1387° C.
$CaO.Al_2O_3$	1587° C.
$3CaO.5Al_2O_3$	1725° C.

Comparing these fusion points, it is evident that the spinel is the most refractory compound available, especially when other properties are considered.

Tubes and crucibles of spinel have been supplied for sometime by the Royal Porcelain Manufactory, Berlin.[6]

Preparation of the Compound. A mixture of 45.2 per cent of flocculent $MgCO_3$ and 54.8 of calcined alumina was ground dry in a ball mill, tempered with water and made into balls about 1¼ in. in diameter. It would be preferable to use for this purpose natural magnesite of sufficient purity because

[6] *Handbuch der gesammten Thonwaaren Industrie*, p. 965. *Dingler's Journal* No. 179, p. 194.

the latter could be handled more easily and would shrink less in calcination. California magnesite is best used in the preparation of this material. The present mixtures were calcined at cone 22. Several other heat treatments were also tried even up to cone 30. The higher the burning, and the more burnings the mixture receives, the better is the result as there is considerable shrinkage, and it should be taken out as nearly as possible.

After calcining it, the material, which was a hard, white, semi-vitreous mass, was ground dry in a mortar. Three sizes were used 40F, 20F, and 20-40. This material when mixed with water has no plasticity, and the fabrication presents a good many difficulties. Ground sand or glass, mixed with water, is about as easy to work.

Casting was tried with all mixtures, and in several ways, with salts, gum, etc.; also thick, thin, in oiled molds, dry molds, wet molds, and in every other way that we could think of. Drawing the slip from the mold presents more trouble. Being so non-plastic, a channel is washed out wherever the slip is poured out, and the walls are of uneven thickness, and the piece warps. Several attempts were made to eliminate this. What few pieces were cast were exceedingly short and very hard to handle at all, when dry.

Jiggering was then tried, and it has worked out very well, with all three sizes of grain. It is essential that the water content be just right and that the molds be coated with a mixture of very fine graphite suspended in oil. The ware releases quickly and should be taken out of the mold as soon as possible. The green ware is tough enough to be handled and can be dried out and set with safety, if reasonable care is used.

The Burning. None of the ware was burned less than twenty hours nor below cone 17. Several pieces burned at the above heat were reheated to cone 34 in a rapid burn, and showed a shrinkage of 16 percent. The harder the calcine is burned, the less the shrinkage will be in the finished ware. The ware burned at cone 17 is cream white, porous, and appears similiar to an ordinary white biscuit body but of rougher texture, on account of being made of coarse grained material. The ware burned to cone 35 was vitrified to a dense translucent body. Examination

of the broken section showed that the vitrification had been carried far enough so that the grains had lost their identity, at least to the naked eye.

Tests made with spinel crucibles show that the material is not easily attacked either by molten slag or iron so long as the exposed surfaces are dense and free from blemishes. The crucibles will not stand exceedingly rapid cooling but will stand ordinary usage. Crucibles burned to cone 35 showed no cracks when taken out of the furnace after fifteen or twenty minutes. Other crucibles did crack, however, when taken right out of the extreme heat with cold tongs, and set on cold bricks.

Spinel should prove very useful in the manufacture of products for use in some metallurgical investigations. Special furnace linings, crucibles, tubes, boats, and similar products which should be very refractory, not easily attacked by gases and remain constant in weight, can be successfully made.

In conclusion, the writer wishes to thank Mr. A. V. Bleininger for many helpful suggestions in carrying on these investigations, also Mr. W. W. McDaniel, who developed the swinging rings for setting tubes, and assisted in the manufacturing of the ware.

DISCUSSION

Mr. Watts: I should like to ask, if you made any determinations as to the actual porosity of either of these mixtures after they were burned?

Mr. Riddle: No, we did not, but it is very evident that the ware burned at the lower temperature is very porous.

Mr. Watts: That is what temperature?

Mr. Riddle: Cone 17, but you will also agree that there is not much porosity in the crucibles burned to cone 34; in fact, the 20 mesh coarse, when it went into the kiln was so coarse that the grains were easily distinguishable. After burning to cone 34 all the 20 mesh grains entirely lost their identity and the whole mass was fused together and quite translucent, as can be seen by holding the sample up to the light.

Mr. Watts: Did you find any evidence of translucency before that high state of vitrification was obtained?

Mr. Riddle: No.

THE EFFECT OF VARIATION IN PRESSURE AND MOISTURE UPON THE FORMING OF DUST PRESSED TILE

BY F. W. WALKER, JR., AND E. G. KERR

The four principal causes to which variation in the porosity of biscuit wall tile are seemingly attributable, are variations in the compounding of the body, the firing, the moisture content of the green body and the pressure which is applied when forming the piece. In the following experimental work the first two of these four variables, namely the body composition and the firing have been kept constant to within practical limits, and the effect of a variation of the other two noted.

The trial pieces were formed on an ordinary large hand press with a 5 foot wheel weighing approximately 325 pounds, and screw of 2¾ in. pitch. The personal factor in the pressing was eliminated entirely by standardizing the drop of the plunger and working the press only under the influence of gravity. The amount of this pressure is rather problematical, but an estimate of its value has been arrived at by comparative means, using copper cubes of exactly 1 in. in all directions annealed to 650° F. and noting the extent of deformation when subjected to a repeated number of licks of the screw press and comparing the results thus attained with those secured by a standard compression machine wherein the load is known. The results of the tests are as follows:

	Specimen No. 1.	Specimen No. 2.	
NO. LICKS	HEIGHT OF CUBE	HEIGHT OF CUBE	TOTAL LOAD SUSTAINED
1	.946	.946	24,900
2	.9195	.9195	28,640
4	.8865	.8865	34,830
6	.8655	.8655	38,200
8	.8515	.8515	40,240
10	.8405	.8405	41,200

Remarks: The height of the specimen No. 2 was measured without removing the load. After applying the highest load, the specimen was removed from the machine and measured with the micrometer. The height was then found to be .8525 in.

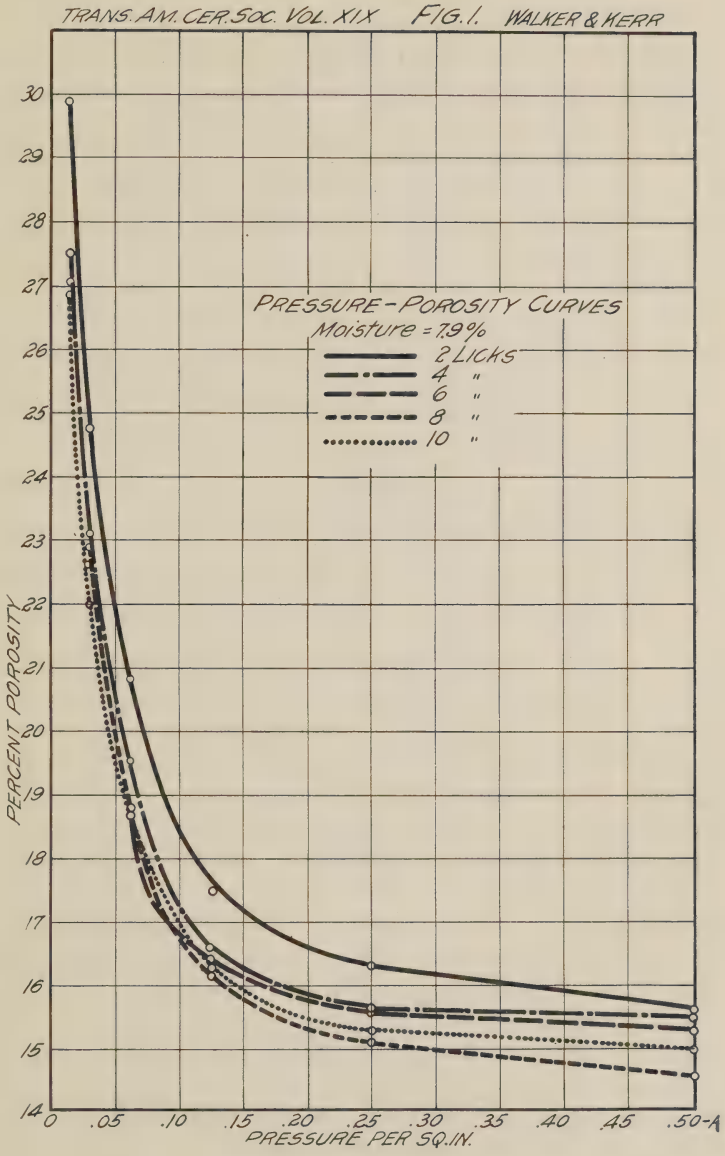
The total pressure applied throughout this experimental work has been kept constant and rather than use any given value as arrived at by the above, the pressure is represented by the letter "K".

Variations in the pressure applied to the dust were obtained by varying the surface of the trial piece. Six circular boxes and dies were made, the diameter of which were made to vary in accordance with the $\sqrt{2}$. This gave a series of areas each subsequent one being twice that of the one just preceding.

A constant body of commercial proportions was used throughout the work, and every possible care was used in the preparation of the various dusts in order to eliminate all such chances of error as might be due to the non-uniformity of the moisture distribution, the grinding and the sieving.

Three dusts of varying moisture content were used for the work, one of average amount, another of comparatively high content, and another of comparatively low content, namely as follows: 11.3, 14.2 and 7.9 percent on the dry weight respectively. The moistures were checked very carefully during the three days required for making up the trial, and when necessary corrections were made. The above figures are average contents, but the variation in all cases amounted to less than ½ percent. Some of the variation in the results obtained are in all probability attributable to this variation in moisture, but better results could hardly be obtained under the conditions.

The trial pieces were pressed by first allowing the plunger of the press to enter the box very slowly and compress the dust only sufficiently to eliminate the larger proportion of air which would under other conditions cause a blowing of the piece. The plunger was then raised to a constant point and allowed to drop on the piece under influence of its own weight and momentum. The number of applications of the same pressure was varied from two to ten licks, two licks at a time. This was for the purpose of noting the effect upon the porosity of a

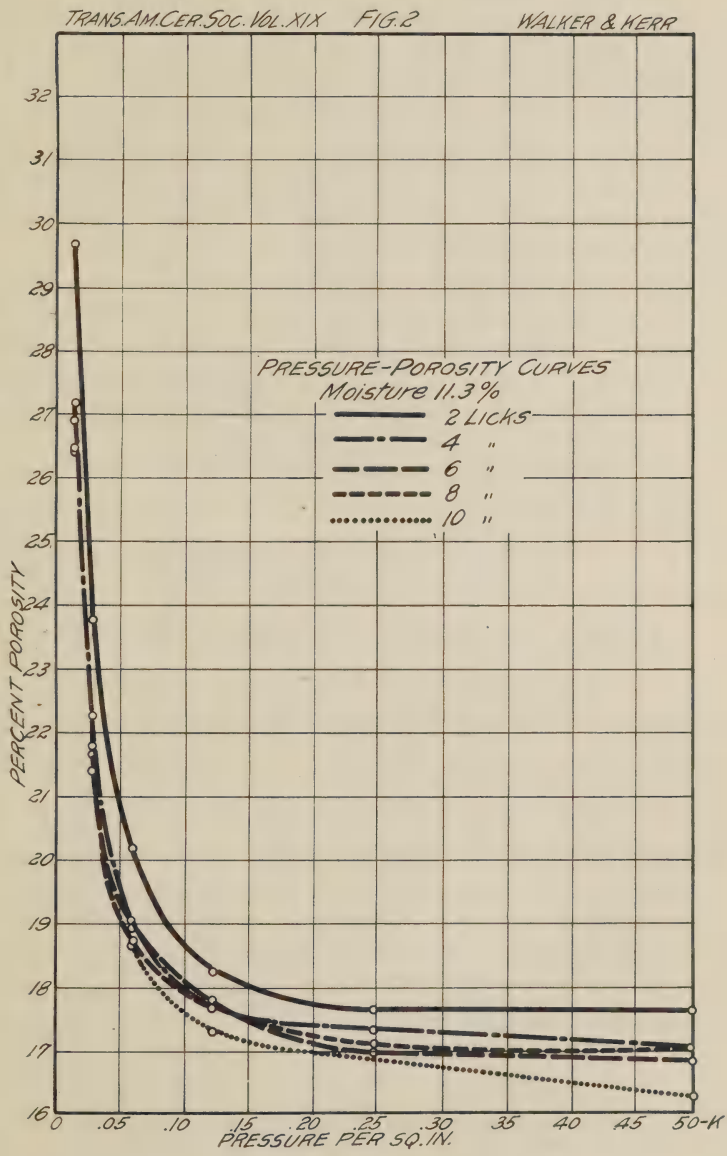

TRANS. AM. CER. SOC. VOL. XIX FIG. 1. WALKER & KERR
PRESSURE - POROSITY CURVES
Moisture = 7.9%
2 LICKS
4 "
6 "
8 "
10 "
PERCENT POROSITY
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
0
.05
.10
.15
.20
.25
.30
.35
.40
.45
.50-A
PRESSURE PER SQ. IN.

repeated application of the same pressure such as is given by the tile presser in forming his piece.

All trials thus formed were placed in saggers and fired together to Mayer cone 10 bent in a part of the kiln giving greatest uniformity. Following the firing, shrinkage was measured to 1/1000th of an inch by means of a micrometer, the percent being figured upon the green length, and the porosity determined by means of the three hour boiling test and volumeter, and the percent of porosity expressed in terms of the displacement.

Two trials were prepared for each determination, one to serve as a check upon the other, and the average figure taken. The results are given in the Tables and Figures.

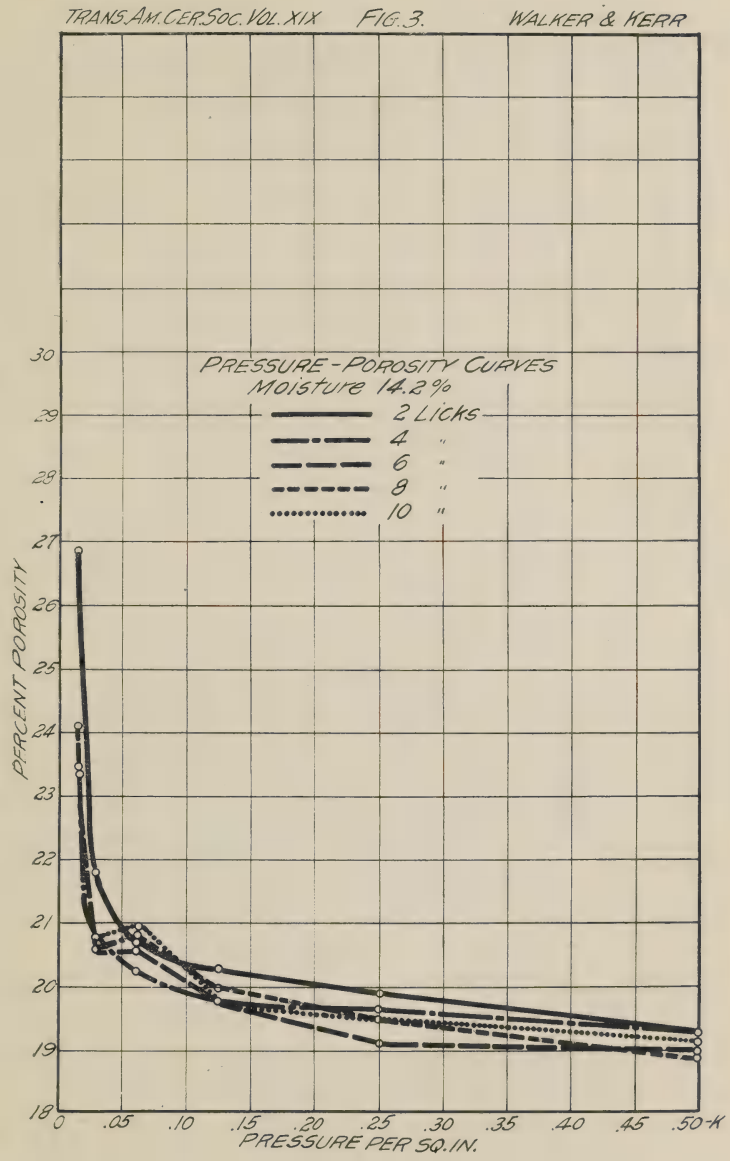
The effect of pressure and the repeated application of the same pressure for various moisture contents is shown clearly by curves of Figs. 1, 2 and 3, each set of curves representing the variation for a given moisture. The vertical coordinate is a measure of the porosity and the horizontal one that of pressure per square inch. The pressure per square inch is expressed by the reciprocal of the area in square inches times the constant "K" previously referred to, which represents the sum total pressure applied. The various applications of the same pressure are plotted along the single pressure coordinate, and the corresponding points connected by varying the line structure. From these curves it can be seen very readily that after the second lick, or following the expulsion of the air from the dust, the decrease in porosity for any repetition of the same pressure is continuous, but decreasing in amount with increase in total pressure per sq. in., or the number of licks applied showing at the higher pressures a confusion of points which are accounted for by slight variations in the moisture, pressure, and measurements which are all within the limit of possible error and especially so with the smallest tile. The variations in the curves representing 6, 8, and 10 licks at point .0625-K, Fig. 3, are due to the blowing of the trials which was not noticed until after the burning. These curves have been so grouped as to show variations in porosity for the dust of varying moisture contents, the horizontal co-ordinates all being of equal elevation.

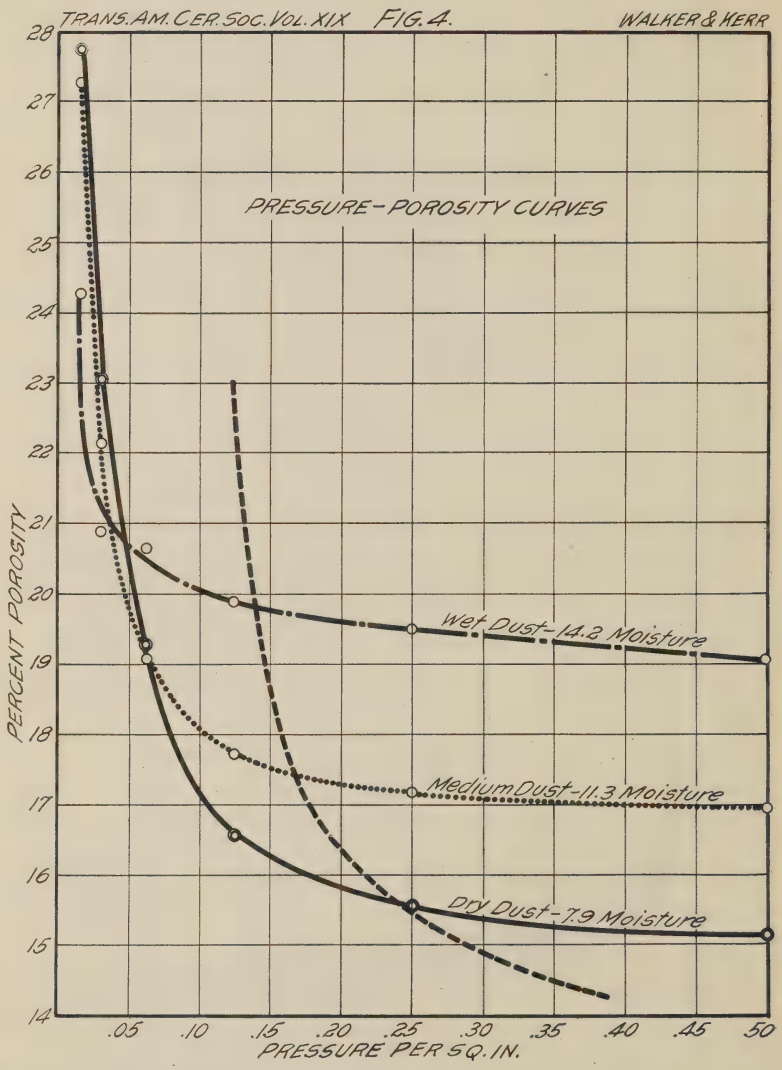

TRANS. AM. CER. SOC. VOL. XIX FIG. 2
WALKER & HERR
PRESSURE-POROSITY CURVES
Moisture 11.3%
2 LICKS
4 "
6 "
8 "
10 "
PERCENT POROSITY
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
0
.05
.10
.15
.20
.25
.30
.35
.40
.45
.50-K
PRESSURE PER SQ. IN.

The various limitations in the porosity for any given moisture content of dust are better shown by the curves of Fig. 4, which are the same as those shown on Fig. 1, 2 and 3, with the exception that the average value of all repeated applications of the same pressure has been plotted, thus reducing the curves from 15 to 3. As a result of the slight variations and irregularities in the results this grouping seems justifiable and aids further in the making of deductions as to the possible limitations of pressure for any given moisture content.

From these curves, the general character of which is the same, the effect of increasing pressure can be readily noted. Wherein pressure per sq. in. is low the variation in porosity for any slight change in pressure is considerable, but with the higher pressures the variation is of secondary importance in securing uniformity to that of the moisture content. The effect of a variation in moisture content upon porosity proves to be of considerable magnitude throughout the range of this investigation and is of about equal extent in the case of the high and low pressure trials with a decrease in the case of pressures approximating .05 K, which is about that of the average hand operated press. This you note corresponds approximately to the pressure indicated by the intersection of the curves and shows, that within the pressure and moisture limits here given the moisture serves both to increase and to decrease porosity, depending upon the pressure applied. This is better shown in the curves of Fig. 6, which are a replotting of the same points shown on Fig. 4, with the exception that the horizontal coordinate is a measure of the moisture in place of the pressure. These curves bring out more clearly the pressure referred to previously, namely, .05 K. Pressures per sq. in below this figure give a decrease in the porosity with increase in moisture content, but above this pressure an increase in porosity. There are, however, insufficient curves to fix definitely the relation between moisture and porosity variations.

By further referencee to the curves of Fig. 4, a line representing the practical limitations of pressure application for any given moisture content can be drawn by assuming some point on each of the three curves whose direction of curvature is the

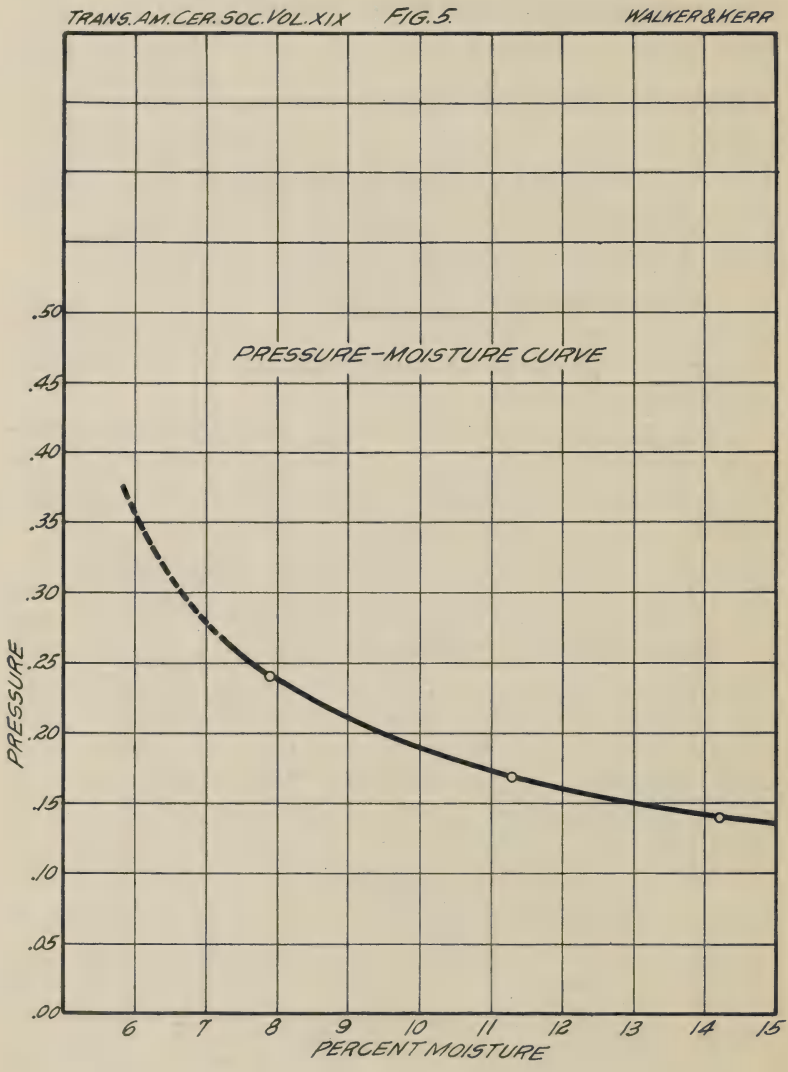

TRANS. AM. CER. SOC. VOL. XIX FIG. 3. WALKER & KERR
PRESSURE - POROSITY CURVES
Moisture 14.2%
2 Licks
4 "
6 "
8 "
10 "
PERCENT POROSITY
30
29
28
27
26
25
24
23
22
21
20
19
18
0 .05 .10 .15 .20 .25 .30 .35 .40 .45 .50-K
PRESSURE PER SQ. IN.

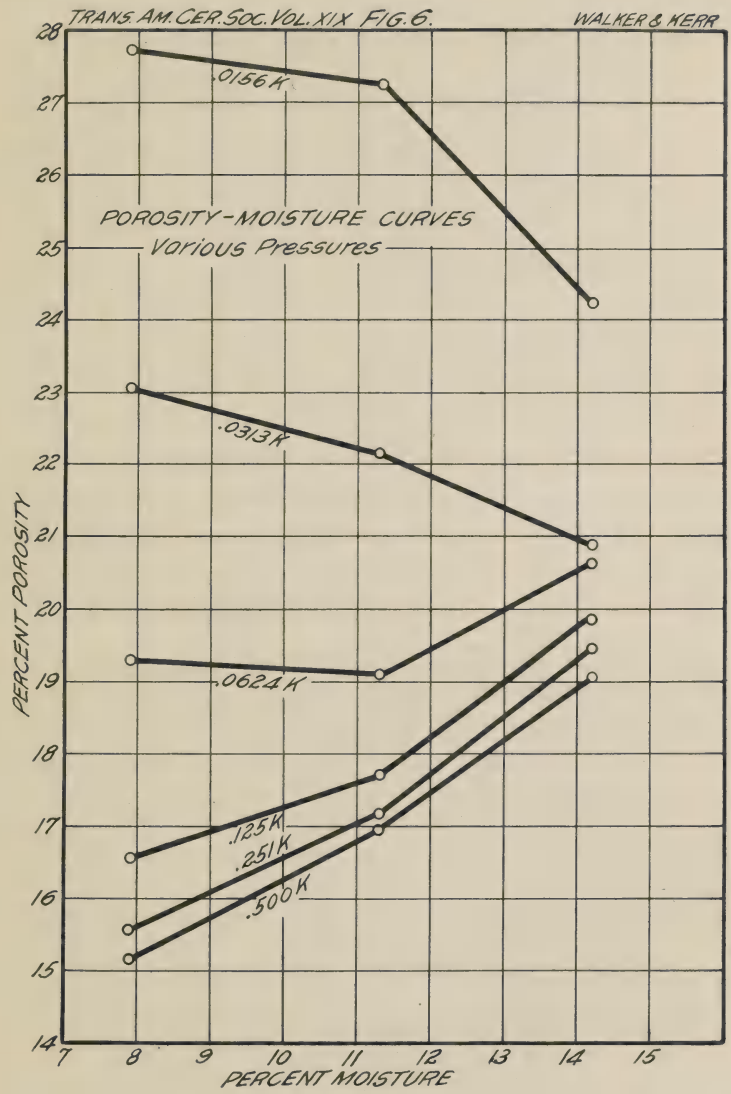

TRANS. AM. CER. SOC. VOL. XIX FIG. 4. WALKER & HERR
PRESSURE-POROSITY CURVES
PERCENT POROSITY
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
Wet Dust-14.2 Moisture
Medium Dust-11.3 Moisture
Dry Dust-7.9 Moisture
.05
.10
.15
.20
.25
.30
.35
.40
.45
.50
PRESSURE PER SQ. IN.

same, and which in this case is represented by 1/.2 K, the tangent of the angle formed by the intersection of the tangent to the curve with the horizontal co-ordinate. This line in this case has been arbitrarily taken and may be shifted either to the right or to the left, according to further investigations, or the opinion of the individual, but such tends to indicate that pressures per sq. in. should equal a certain amount for any given moisture content to prevent excessive porosity variations due to slight variations in the pressure applied, but any increase much beyond this amount does not give a justifiable reduction in porosity and tends to increase the wear upon the press.

A better understanding of the result so obtained can be had by a replotting of the curve, using the vertical co-ordinate as a measure of the pressure and horizontal one as a measure of the moisture content. See Fig. 5.

The shrinkage curves for these various pressure applications combined, as in the case of curves shown on Fig. 4, are shown on Fig. 7. As can be easily noted the shrinkage decreases with increase of pressure for all dusts to a point approximating .25 K, beyond which the shrinkage increases. In the entire 30 trials determining these three points no exceptions to this condition were had. It may be possible that this is due to some variation in the time-temperature curves for the various trials, but such does not seem possible to the writers, the trials all being burned together and under apparently the same conditions. To insure against any mistakes, however, the results were checked by pressing new trials under average conditions using 4 licks and 12.36 percent moisture, and the results thus obtained are as follows:


TRANS. AM. CER. SOC. VOL. XIX FIG. 5. WALKER & KERR
PRESSURE-MOISTURE CURVE
PRESSURE
.50
.45
.40
.35
.30
.25
.20
.15
.10
.05
.00
6
7
8
9
10
11
12
13
14
15
PERCENT MOISTURE


TRANS. AM. CER. SOC. VOL. XIX FIG. 6.
WALKER & KERR
POROSITY-MOISTURE CURVES
Various Pressures
.0156 K
.0313 K
.0624 K
.125 K
.251 K
.500 K
PERCENT POROSITY
PERCENT MOISTURE
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
7
8
9
10
11
12
13
14
15

NO. OF BOX	TRIAL	GREEN LENGTH	AV'G.	BURNED LENGTH	AV'G.	SHRINKAGE	SHRINKAGE
							percent
1	1	9.0400		8.5625			
1	2	9.0390	.0395	8.5620	.5622	.4773	5.16
2	1	6.4185		6.073			
2	2	6.4190	.4187	6.080	.0705	.3482	5.43
3	1	4.5220		4.323			
3	2	4.5230	.5225	4.311	.3110	.2110	4.68
4	1	3.1975		3.053			
4	2	3.1985	.1980	3.060	.0505	.1475	4.61
5	1	2.2630		2.163			
5	2	2.2630	.2630	2.161	.1560	.1070	4.74
6	1	1.6010		1.527			
6	2	1.6010	.6010	1.523	.5190	.0820	5.12

These results bear out the previous findings. It is also apparent from these curves that the shrinkage for any given pressure, especially when greater than .05 K, will decrease with decrease in moisture content of the dust within the limits here studied.

From the curves a better understanding of many of the difficulties experienced in the pressing of dust-pressed tile can be had and especially is such the case with the pressing of trim wherein it becomes difficult to secure a uniform application of the same pressure. With the shrinkage variation as the result of non-homogeneity of the moisture distribution and varying pressure, stresses result which lead to crooking and cracking of the ware.

The writers wish at this time to express their appreciation of the assistance of Mr. A. V. Bleiniger in securing the results relative to the compression test upon the copper cube.

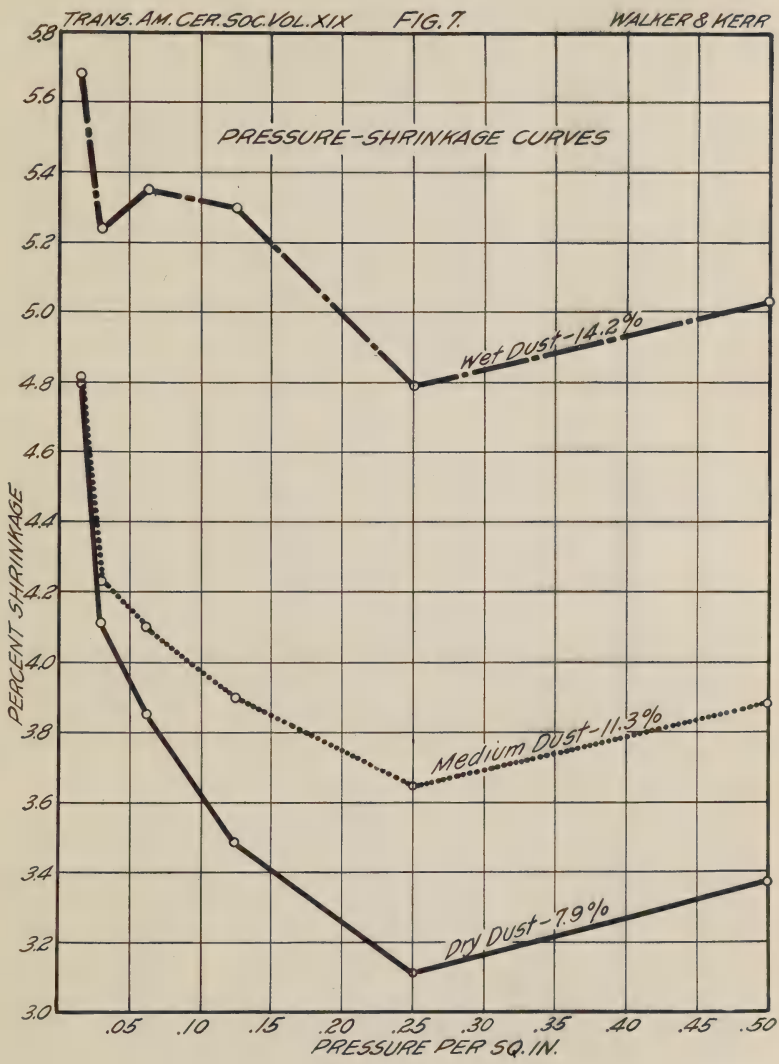

TRANS. AM. CER. SOC. VOL. XIX
FIG. 7.
WALKER & KERR
PRESSURE-SHRINKAGE CURVES
Wet Dust-14.2%
Medium Dust-11.3%
Dry Dust-7.9%
PERCENT SHRINKAGE
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
.05
.10
.15
.20
.25
.30
.35
.40
.45
.50
PRESSURE PER SQ. IN.

TABLE I

SIZE	DUST	LICKS	GREEN LENGTH	BURNED LENGTH	DIFFERENCE	AV'G. SHRKG.	POROSITY	AV'G. POROS.
	percent		*inches*	*inches*		*percent*		
1.596	14.2	2	1.596	1.515	.081	....	19.26	....
1.596	14.2	2	1.596	1.516	.080	5.045	19.19	19.23
1.596	14.2	4	1.596	1.518	.078	....	19.14	....
1.596	14.2	4	1.596	1.516	.080	4.95	19.39	19.26
1.596	14.2	6	1.596	1.516	.080	....	18.65	....
1.596	14.2	6	1.596	1.516	.080	5.01	19.20	18.92
1.596	14.2	8	1.596	1.513	.083	....	18.18	....
1.596	14.2	8	1.596	1.517	.079	5.075	19.50	18.84
1.596	14.2	10	1.596	1.517	.079	....	19.27	....
1.596	14.2	10	1.596	1.513	.083	5.075	18.90	19.08
			1.596	1.515	.080	5.031	....	19.06
1.596	11.2	2	1.596	1.534	.062	....	17.48	....
1.596	11.3	2	1.596	1.534	.062	3.89	17.76	17.62
1.596	11.3	4	1.596	1.533	.063	....	17.11	....
1.596	11.3	4	1.596	1.533	.063	3.95	16.94	17.02
1.596	11.3	6	1.596	1.534	.062	....	16.88	....
1.596	11.3	6	1.596	1.534	.062	3.89	16.74	16.81
1.596	11.3	8	1.596	1.536	.060	....	17.01	....
1.596	11.3	8	1.596	1.535	.061	3.79	17.03	17.02
1.596	11.3	10	1.596	1.534	.062	....	16.02	....
1.596	11.3	10	1.596	1.533	.063	3.92	16.48	16.25
			1.596	1.534	.062	3.88	....	16.94
1.596	7.9	2	1.596	1.542	.054	....	15.50	....
1.596	7.9	2	1.596	1.542	.054	3.38	15.70	15.60
1.596	7.9	4	1.596	1.542	.054	....	15.74	....
1.596	7.9	4	1.596	1.541	.055	3.415	15.15	15.49
1.596	7.9	6	1.596	1.543	.053	....	14.90	....
1.596	7.9	6	1.596	1.541	.055	3.385	15.59	15.24
1.596	7.9	8	1.596	1.543	.053	....	14.54	....
1.596	7.9	8	1.596	1.543	.053	3.32	14.53	14.53
1.596	7.9	10	1.596	1.542	.054	....	14.73	....
1.596	7.9	10	1.596	1.543	.053	3.35	15.17	14.95
			1.596	1.541	.053	3.37	....	15.16

TABLE II

SIZE	DUST	LICKS	GREEN LENGTH	BURNED LENGTH	DIFFERENCE	AV'G. SHRKG.	POROSITY	AV'G. POROS.
	percent		*inches*	*inches*		*percent*		
2.250	14.2	2	2.250	2.142	.108	....	19.95	....
2.250	14.2	2	2.250	2.142	.108	4.80	19.78	19.86
2.250	14.2	4	2.250	2.142	.108	....	19.61	....
2.250	14.2	4	2.250	2.139	.111	4.865	19.62	19.61
2.250	14.2	6	2.250	2.144	.106	....	19.11	....
2.250	14.2	6	2.250	2.147	.103	4.645	19.01	19.06
2.250	14.2	8	2.250	2.144	.106	....	18.97	....
2.250	14.2	8	2.250	2.140	.110	4.80	19.95	19.46
2.250	14.2	10	2.250	2.142	.108	....	19.09	....
2.250	14.2	10	2.250	2.140	.110	4.845	19.79	19.44
			2.250	2.142	.107	4.791	....	19.48
2.250	11.3	2	2.250	2.167	.083	....	17.70	....
2.250	11.3	2	2.250	2.167	.083	3.69	17.55	17.62
2.250	11.3	4	2.250	2.167	.083	....	17.24	....
2.250	11.3	4	2.250	2.167	.083	3.69	17.36	17.30
2.250	11.3	6	2.250	2.168	.082	....	17.00	....
2.250	11.3	6	2.250	2.169	.081	3.62	16.99	16.99
2.250	11.3	8	2.250	2.168	.082	....	17.16	....
2.250	11.3	8	2.250	2.168	.082	3.64	17.00	17.08
2.250	11.3	10	2.250	2.169	.081	....	16.98	....
2.250	11.0	10	2.250	2.168	.082	3.62	16.91	16.94
			2.250	2.167	.082	3.65	....	17.18
2.250	7.9	2	2.250	2.178	.072	....	16.30	....
2.250	7.9	2	2.250	2.178	.072	3.20	16.28	16.29
2.250	7.9	4	2.250	2.179	.071	....	15.57	....
2.250	7.9	4	2.250	2.179	.071	3.16	15.67	15.62
2.250	7.9	6	2.250	2.181	.069	....	15.51	....
2.250	7.9	6	2.250	2.180	.070	3.09	15.66	15.58
2.250	7.9	8	2.250	2.181	.069	....	15.13	....
2.250	7.9	8	2.250	2.182	.068	3.045	15.05	15.09
2.250	7.9	10	2.250	2.181	.069	....	15.20	....
2.250	7.9	10	2.250	2.182	.068	3.045	15.35	15.27
			2.250	2.180	.069	3.108	....	15.57

TABLE III

SIZE	DUST	LICKS	GREEN LENGTH	BURNED LENGTH	DIFFERENCE	AV'G. SHRKG.	POROSITY	AV'G. POROS.
	percent		*inches*	*inches*		*percent*		
3.191	14.2	2	3.191	3.022	.169	....	20.08	....
3.191	14.2	2	3.191	3.022	.169	5.30	20.41	20.25
3.191	14.2	4	3.191	3.021	.170	....	19.68	....
3.191	14.2	4	3.191	3.018	.173	5.375	19.78	19.73
3.191	14.2	6	3.191	3.021	.170	....	19.87	....
3.191	14.2	6	3.191	3.021	.170	5.33	19.57	19.72
3.191	14.2	8	3.191	3.024	.167	....	20.00	....
3.191	14.2	8	3.191	3.022	.169	5.265	19.95	19.97
3.191	14.2	10	3.191	3.024	.167	....	19.61	....
3.191	14.2	10	3.191	3.025	.166	5.215	19.92	19.76
			3.191	3.022	.169	5.297	....	19.88
3.191	11.3	2	3.191	3.063	.128	....	18.37	....
3.191	11.3	2	3.191	3.063	.128	4.01	18.02	18.19
3.191	11.3	4	3.191	3.067	.124	....	17.73	....
3.191	11.3	4	3.191	3.068	.123	3.87	17.57	17.65
3.191	11.3	6	3.191	3.067	.124	....	17.73	....
3.191	11.3	6	3.191	3.066	.125	3.905	17.82	17.77
3.191	11.3	8	3.191	3.069	.122	....	17.51	....
3.191	11.3	8	3.191	3.069	.122	3.82	17.79	17.65
3.191	11.3	10	3.191	3.068	.123	....	17.39	....
3.191	11.3	10	3.191	3.068	.123	3.85	17.17	17.28
			3.191	3.066	.124	3.891	....	17.71
3.191	7.9	2	3.191	3.075	.116	....	18.04	....
3.191	7.9	2	3.191	3.076	.115	3.62	16.90	17.47
3.191	7.9	4	3.191	3.081	.110	....	16.63	....
3.191	7.9	4	3.191	3.080	.111	3.465	16.53	16.58
3.191	7.9	6	3.191	3.082	.109	....	16.02	....
3.191	7.9	6	3.191	3.081	.110	3.435	16.75	16.38
3.191	7.9	8	3.191	3.081	.110	....	16.31	....
3.191	7.9	8	3.191	3.083	.108	3.415	15.94	16.12
3.191	7.9	10	3.191	3.080	.111	....	16.21	....
3.191	7.9	10	3.191	3.082	.109	3.45	16.28	16.24
			3.191	3.080	.110	3.477	....	16.56

TABLE IV

SIZE	DUST	LICKS	GREEN LENGTH	BURNED LENGTH	DIFFERENCE	AV'G. SHRKG.	POROSITY	AV'G. POROS.
	percent		*inches*	*inches*		*percent*		
4.515	14.2	2	4.515	4.258	.257	....	20.76	....
4.515	14.2	2	4.515	4.269	.246	5.57	20.58	20.67
4.515	14.2	4	4.515	4.272	.243	....	20.64	....
4.515	14.2	4	4.515	4.265	.250	5.46	19.80	20.22
4.515	14.2	6	4.515	4.280	.235	....	20.24	....
4.515	14.2	6	4.515	4.274	.241	5.27	20.89	20.56
4.515	14.2	8	4.515	4.284	.231	....	20.83	....
4.515	14.2	8	4.515	4.282	.233	5.14	20.73	20.78
4.515	14.2	10	4.515	4.276	.239	....	20.64	....
4.515	14.2	10	4.515	4.282	.243	5.34	21.21	20.92
			4.515	4.274	.241	5.35	....	20.63
4.515	11.3	2	4.515	4.328	.187	....	20.09	....
4.515	11.3	2	4.515	4.324	.191	4.185	20.17	20.13
4.515	11.3	4	4.515	4.334	.181	....	19.17	....
4.515	11.3	4	4.515	4.328	.187	4.075	18.85	19.01
4.515	11.3	6	4.515	4.327	.188	....	19.09	....
4.515	11.3	6	4.515	4.329	.186	4.14	18.72	18.90
4.515	11.3	8	4.515	4.334	.181	....	18.82	....
4.515	11.3	8	4.515	4.333	.182	4.02	18.59	18.70
4.515	11.3	10	4.515	4.328	.187	....	18.46	....
4.515	11.3	10	4.515	4.334	.181	4.075	18.79	18.62
			4.515	4.329	.185	4.099	....	19.07
4.515	7.9	2	4.515	4.331	.184	....	20.87	....
4.515	7.9	2	4.515	4.331	.184	4.08	20.70	20.78
4.515	7.9	4	4.515	4.340	.175	....	19.50	....
4.515	7.9	4	4.515	4.339	.176	3.89	19.52	19.51
4.515	7.9	6	4.515	4.344	.171	....	18.51	....
4.515	7.9	6	4.515	4.343	.172	3.80	18.98	18.74
4.515	7.9	8	4.515	4.341	.174	....	18.37	....
4.515	7.9	8	4.515	4.347	.168	3.795	18.93	18.65
4.515	7.9	10	4.515	4.348	.167	....	18.78	....
4.515	7.9	10	4.515	4.348	.167	3.71	18.88	18.73
			4.515	4.339	.173	3.855	....	19.28

TABLE V

SIZE	DUST	LICKS	GREEN LENGTH	BURNED LENGTH	DIFFERENCE	AV'G. SHRKG.	POROSITY	AV'G. POROS.
	percent		*inches*	*inches*		*percent*		
6.372	14.2	2	6.372	6.040	.332	....	21.71	....
6.372	14.2	2	6.372	6.038	.334	5.22	21.86	21.78
6.372	14.2	4	6.372	6.040	.332	....	20.92	....
6.372	14.2	4	6.372	6.037	.335	5.235	20.60	20.76
6.372	14.2	6	6.372	6.028	.344	....	20.54	....
6.372	14.2	6	6.372	6.029	.343	5.385	20.60	20.57
6.372	14.2	8	6.372	6.041	.331	....	20.64	....
6.372	14.2	8	6.372	6.040	.332	5.20	20.53	20.58
6.372	14.2	10	6.372	6.044	.328	....	20.74	....
6.372	14.2	10	6.372	6.045	.327	5.135	20.73	20.73
			6.372	6.038	.333	5.235	....	20.88
6.372	11.3	2	6.372	6.082	.290	....	23.60	....
6.372	11.3	2	6.372	6.086	.286	4.515	23.84	23.72
6.372	11.3	4	6.372	6.096	.276	....	22.22	....
6.372	11.3	4	6.372	6.097	.275	4.325	22.18	22.20
6.372	11.3	6	6.372	6.098	.274	....	21.62	....
6.372	11.3	6	6.372	6.106	.266	4.24	21.87	21.75
6.372	11.3	8	6.372	6.114	.258	....	21.67	....
6.372	11.3	8	6.372	6.113	.259	4.06	21.55	21.61
6.372	11.3	10	6.372	6.114	.258	....	21.21	....
6.372	11.3	10	6.372	6.116	.256	4.03	21.48	21.34
			6.372	6.102	.269	4.234	....	22.12
6.372	7.9	2	6.372	6.096	.276	....	24.68	....
6.372	7.9	2	6.372	6.100	.272	4.30	24.81	24.74
6.372	7.9	4	6.372	6.099	.273	....	22.88	....
6.372	7.9	4	6.372	6.105	.267	4.235	23.26	23.07
6.372	7.9	6	6.372	6.113	.259	....	22.93	....
6.372	7.9	6	6.372	6.118	.254	4.025	22.80	22.86
6.372	7.9	8	6.372	6.120	.252	....	22.49	....
6.372	7.9	8	6.372	6.119	.253	3.955	22.69	22.59
6.372	7.9	10	6.372	6.116	.256	....	21.90	....
6.372	7.9	10	6.372	6.117	.255	4.01	22.03	21.96
			6.372	6.110	.265	4.105	....	23.04

TABLE VI

SIZE	DUST	LICKS	GREEN LENGTH	BURNED LENGTH	DIFFERENCE	AV'G. SHRKG.	POROSITY	AV'G. POROS.
	percent		*inches*	*inches*		*percent*		
9.046	14.2	2	9.046	8.531	.515	....	26.25	....
9.046	14.2	2	9.046	8.531	.515	5.69	27.45	26.85
9.046	14.2	4	9.046	8.531	.515	....	24.41	....
9.046	14.2	4	9.046	8.546	.500	5.60	23.75	24.08
9.046	14.2	6	9.046	8.531	.515	....	23.45	....
9.046	14.2	6	9.046	8.500	.546	5.86	23.35	23.40
9.046	14.2	8	9.046	8.531	.515	....	22.91	....
9.046	14.2	8	9.046	8.546	.500	5.60	23.95	23.43
9.046	14.2	10	9.046	8.531	.515	....	23.41	....
9.046	14.2	10	9.046	8.531	.515	5.69	23.42	23.41
			9.046	8.531	.515	5.68	....	24.23
9.046	11.3	2	9.046	8.591	.455	....	29.71	....
9.046	11.3	2	9.046	8.598	.448	4.99	29.55	29.63
9.046	11.3	4	9.046	8.603	.443	....	27.35	....
9.046	11.3	4	9.046	8.588	.458	4.98	26.95	27.15
9.046	11.3	6	9.046	8.625	.421	....	26.75	....
9.046	11.3	6	9.046	8.623	.423	4.67	27.01	26.88
9.046	11.3	8	9.046	8.614	.432	....	26.21	....
9.046	11.3	8	9.046	8.623	.423	4.73	26.61	26.41
9.046	11.3	10	9.046	8.625	.421	....	26.41	....
9.046	11.3	10	9.046	8.626	.420	4.65	26.33	26.37
			9.046	8.611	.434	4.80	....	27.28
9.046	7.9	2	9.046	8.600	.446	....	29.89	....
9.046	7.9	2	9.046	8.575	.471	5.07	29.90	29.89
9.046	7.9	4	9.046	8.607	.439	....	27.80	....
9.046	7.9	4	9.046	8.597	.449	4.91	27.21	27.50
9.046	7.9	6	9.046	8.620	.426	....	28.09	....
9.046	7.9	6	9.046	8.622	.424	4.70	26.95	27.52
9.046	7.9	8	9.046	8.621	.425	....	26.65	....
9.046	7.9	8	9.046	8.621	.425	4.70	27.00	26.82
9.046	7.9	10	9.046	8.621	.425	....	27.35	....
9.046	7.9	10	9.046	8.621	.425	4.70	26.75	27.05
			9.046	8.610	.435	4.81	....	27.75

THE EFFECT OF THE POROSITY OF THE BODY AND THE MOISTURE CONTENT OF THE GLAZE IN THE APPLICATION OF MAT GLAZES

BY F. S. HUNT

The application of mat glazes to biscuit bodies offers difficulties not encountered in the use of bright glazes. This is emphasized in cases where the delicate veining from the healed drying cracks is desired. To secure these markings with a uniformity of effect from burn to burn requires a most minute duplication of conditions. The attempt to secure like markings on flat tile, and on trim tile (angles, stops, curved tile, etc.) is also difficult. A glaze applied simultaneously to flat and trim tile may behave admirably on the trim and crawl into separate glaze sections on the flat or vice versa.

The present paper does not deal with mat glazes from the standpoint of formulae and composition, but treats only of the matter of their application. It does not touch upon the subject of the addition of gums and salts in the securing of a better cohesion within the glaze and adhesion between the glaze and body. The object of this paper is to first study the effect on the resultant mat texture when applying the glaze to tile of different porosities, also to note the effect of the moisture content of the glaze on this same texture. A second part of the object was to determine whether this variation in texture was caused solely by the thickness of dip, which in turn was influenced by the porosity of the body and moisture content of the glaze, or if there were a second factor, independent of the thickness of dip, due to the rate at which the water was removed from the glaze by absorption into the body and evaporation to the air. For example: if the moisture content is very low and the porosity is high, the drying cracks appear as a flash immediately after the dipping, while with a lower porosity and higher moisture content, the drying cracks become visible to the eye only after a considerable

amount of time has elapsed. In the first case it is evident that practically all of the water from the glaze has been absorbed by the body. In the latter case an appreciable amount has been evaporated by the air.

Outline of the Work. Three representative raw lead mat glazes were taken. These were prepared in the usual manner. In order that the effect of the raw clay might not vary, the same quantity, .05 equivalent was used in each case, the balance of the clay required being added as calcined clay. The glazes were brought to a thick consistency, and each glaze divided into eight parts, seven of these parts were diluted with increasing amounts of water, so that of each glaze there were eight portions of different moisture contents. These portions were lettered from A to H in the order of increasing moisture content. The percent moisture content of each was determined in a 50-gram sample.

The tile used were of the same composition but varying in porosity from 14 percent to 31 percent, this variation being secured by variation of moisture content of the dust and variation of pressure as described by Walker and Kerr in their paper, in this volume.

Ten tile covering the range of porosity were dipped with each moisture content of each glaze, making 240 trials in all. In dipping, the effort was made to secure a uniform dip of approximately one-tenth inch in thickness. This was applied at one time. The porosity and volume of each piece having been determined, the area to be glazed was calculated by assuming that the faces of the trials were parallel planes and that the sides were perpendicular to these planes. The volume divided by the thickness gave the area. The thickness taken was the average of three micrometer measurements of each trial.

The weight of the glazed tile, after burning, less the weight of the dry biscuit tile gave the weight of the fused glaze. This weight in grams divided by the area in square cm. gave the weight per unit area, a value which could be compared for the different trials.

The trials were placed flat in luted saggers and burned to cone 1 in 24 hours. The trials were all in the same section of the kiln so that the heat treatment received was uniform.

Results. The trials are arranged on the boards in the same order as on the tables of data; the moisture content of the glaze increases in a horizontal direction from left to right following the letters A to H, the porosity of the body varies in a vertical direction, decreasing from the top to the bottom following the numbers 1 to 10.

In glaze I, trials within the area A-1, A-5, G-1, and G-5, (a porosity range of 23 to 31 percent and a range of moisture content of 65 percent to 104 percent) have the tendency to crawl. In some cases the white tile shows between glaze sections, in other cases this tendency is shown by hummocks and depressions of the glaze surface, and the drying cracks are not well fused over. A comparatively narrow field extending from A-6, A-7, and A-8, across the series to H-5, H-6, and H-7 (porosity 18 to 23 percent, moisture 65 to 105 percent) contains with a few exceptions the desirably marked smooth mat glazes. Below this field the marking decreases leaving glazes flat in appearance, lacking the character and attractiveness of the well marked glazes.

Trial A-1 with the body having a porosity of 30.65 percent and the glaze having a moisture content of 65 percent, has 0.342 gms. of fused glaze per sq. cm. H-1, with the body having a porosity of 29.75 percent, and the glaze a moisture content of 105 percent has 0.109 gms. of fused glaze per sq. cm. The decrease between these two limits is not uniform, the greatest decrease coming between a moisture content of 65 percent and that of 69 percent. In the vertical direction the decrease is more uniform. A-10 with porosity of body at 14.73 percent and moisture content of glaze at 65 percent has 0.162 gms. of fused glaze per sq. cm. The fourth corner H-10, porosity of body 15.70 percent, moisture content of glaze 105 percent, has 0.069 gms. of fused glaze per sq. cm.

Arranging the trials in the order of their weight of glaze per unit area, regardless of the porosity of the body or moisture content of the glaze, gave a surprisingly uniform range, the glazes dividing themselves into three groups; 1st, those having a tendency to crawl and having an irregular surface had a weight of glaze per sq. cm. of .136 grams or over, 2nd, smooth well marked mats with the drying cracks healed had a weight of

TRANS. AM. CER. SOC. VOL. XIX FIG. 4. HUNT

APPEARANCE OF TRIALS

GLAZE I

No.	A	B	C	D	E	F	G	H
1	A	A	B	B	B	A	A	B
2	B	B	B	B	B	B	B	C
3	B	B	B	B	C	A	A	A
4	B	A	B	B	B	C	C	C
5	B	B	C	C	C	B	C	C
6	B	C	C	C	C	B	C	C
7	B	B	D	D	H	D	D	D
8	D	D	D	E	E	E	E	E
9	B	D	D	E	E	E	D	E
10	B	D	E	E	E	E	E	E

A - Glaze separated into sections
B - Unfused drying cracks
C - Well marked from drying cracks
D - Slightly marked from drying cracks
E - Smooth, not marked
F - Surface pinholed
G - Color poor
H - Irregular

glaze per sq. cm. of from 0.100 gram to 0.135 gram; 3rd, those deficient in marking and of smooth surface, below 0.100 gram per sq. cm. There were a few exceptions to this grouping, some of the pieces which were taken from round tile made on the 9 in. and 6 in. diameter dies were much denser in the center than on the outside edge. Therefore the porosity for these pieces is only an average, and also the weight of glaze per unit area is only an average. These tile in a number of cases show a crawled texture at the edge and smoothness on the denser part of the tile at the center.

Glaze II as a whole has not received sufficient heat treatment for its best development. For this reason there are no trials in which the drying cracks are thoroughly healed. Trials H-2, 3, 4, and 5, and A-6, most nearly approach this condition. A-6 seems out of place in this respect, and I can only account for it by assuming an error either in the porosity determination or in the weight of the biscuit tile.

The limits observed in this glaze are approximately the same as those reported for Glaze I.

In arranging these trials according to weight of glaze per unit area, there were only two groups; 1st, the group of crawling and unfused drying cracks, and 2nd, the group of little or no drying marking. The dividing line between the two groups was approximately at 0.100 gram per sq. cm. checking the lower limit observed in Glaze I.

Glaze III is in many ways the most pleasing of the three glazes. In no case did the tendency to crawl become so marked as to show the tile between the glaze sections, and a very good range of mat textures is shown. The field of unfused drying cracks runs approximately diagonally across the upper left corner from trial A-6 to H-1.

The area of unmarked glazes is small and located at the lower right corner extending from E-10 to H-8. The large field between these two areas mentioned contains smooth desirable mats with the veining from the healed drying cracks differing only in the quantity of the marking.

Arranging this series in the order of unit weight of glaze per sq. cm. the three groups are divided as follows; 1st, those

TRANS. AM. CER. SOC. VOL. XIX FIG. 5. HUNT

APPEARANCE OF TRIALS

GLAZE 2

No.	A	B	C	D	E	F	G	H
1	A	A	A	A	A	A	A	B
2	A	A	A	A	A	A	A	B
3	A	A	A	A	A	A	A	B
4	A	A	A	A	A	A	A	B
5	A	A	A	A	A	A	A	B
6	B	A	B	B	B	B	B	D
7	B	B	B	B	B	B	B	E
8	A	A	E	B	B	B	E	E
9	A	B	B	B	B	B	E	E
10	A	B	B	E	E	E	E	E

A - Glaze separated into sections
B - Unfused drying cracks
C - Well marked from drying cracks
D - Slightly marked from drying cracks
E - Smooth, not marked
F - Surface pinholed
G - Color poor
H - Irregular

TRANS. AM. CER. SOC. VOL. XIX FIG. 6. HUNT

APPEARANCE OF TRIALS

GLAZE 3

No.	A	B	C	D	E	F	G	H
1	B	B	B	C	B	B-G	B-G	B
2	B-G	B	B-G	B	B	B	B	C
3	B	B	B	B	B	B	C	C
4	B-G	B	B-G	C	B	B	C	C
5	B-G	B	C	C	C-G	C-G	C-G	B
6	B-G	C	C	C	C-G	C-G	C	C
7	C	C	C	C	C	E	B	C
8	B	C	C	C	C	D	D	E
9	B	C	C	C	E	E	B	E
10	B	C	E	D	E	D	E	E

A- Glaze separated into sections
B- Unfused drying cracks
C- Well marked from drying cracks
D- Slightly marked from drying cracks
E- Smooth, not marked
F- Surface pinholed
G- Color poor
H- Irregular

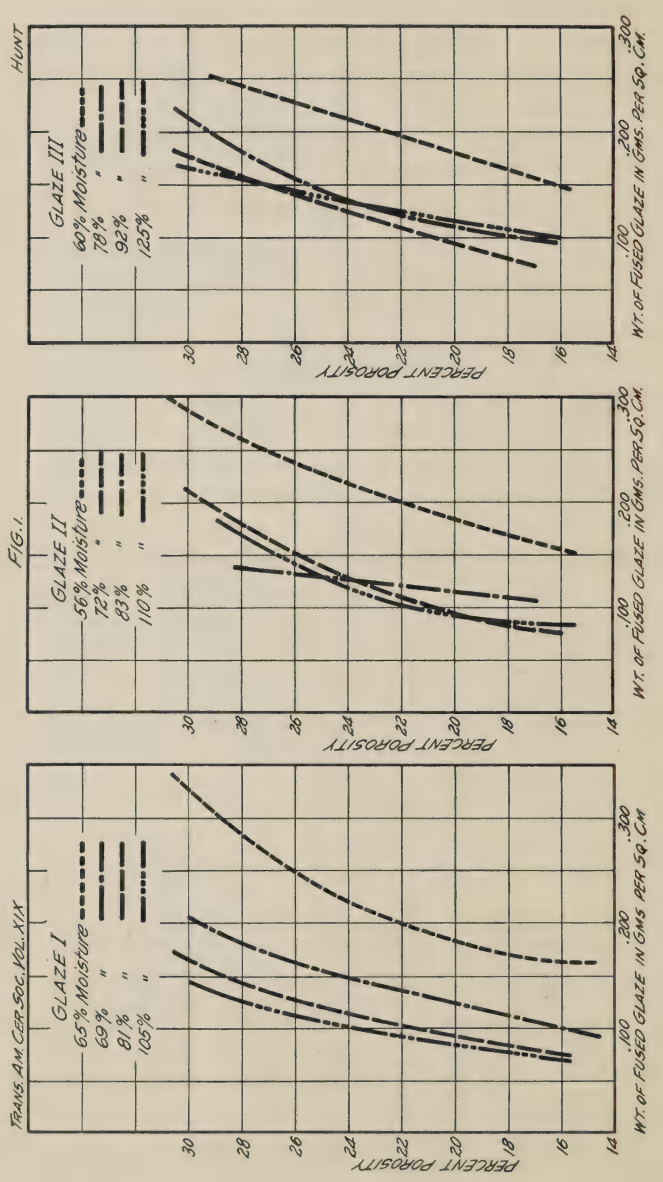
having drying cracks unfused have a weight of glaze of 0.139 grams per sq. cm. or over; 2nd, those of desirable texture having well fused veining from the drying cracks have a range of glaze weight from .100 to .139 grams per sq. cm.; 3rd, those having little or no marking from drying cracks, have less than .100 grams per sq. cm.

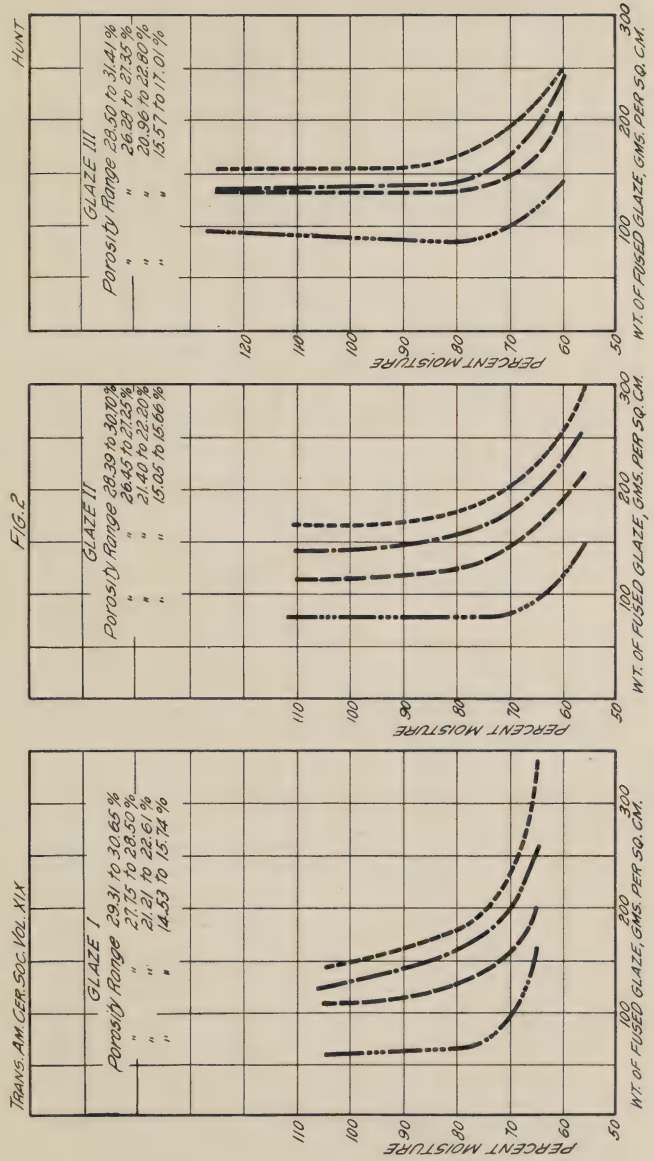
The upper limit of desirable glazes was quite closely defined; for five trials having a unit weight of 0.139 gms, three were classed as desirable and two in the class of the too heavily dipped mats.

In any work in which the personal element of the worker affects the results, mathematical statements or deductions are only posible when a sufficiently large number of observations have been made to insure a correct average. With the limited work of this paper, it is not justifiable to attempt to do this; but in studying the relative effects of the porosity of the body and the moisture content of the glaze in their effect on mat glaze texture through the control of the weight of glaze per unit area, it may be interesting to plot a few curves from the figures obtained. Plotting porosity of the body against weight of glaze per unit area is shown in Fig. 1 for the various moisture contents of the three glazes. Moisture contents against weight of glaze per unit area for approximately constant porosities of the body is shown for the three glazes in Fig. 2. These are only average curves as due to the natural variations, it was impossible to follow the points closely. These curves can not be considered as absolute in their values, but merely as illustrative of the relative effect of the two variables in controlling the weight of glaze per unit area.

Conclusions. The weight of glaze per unit area is the determining factor in the control of mat texture. The limits observed in this paper for the three glazes investigated were that desirable effects could be obtained with a weight of from .100 to .135 grams per sq. cm. How wide an application these figures may have, remains for further investigation.

No effect of the porosity of the body and moisture content of the glaze, other than in the control of the weight of glaze per unit area, could be observed.


TRANS. AM. CER. SOC. VOL. XIX
GLAZE I
65% Moisture
69% "
81% "
105% "
PERCENT POROSITY
WT. OF FUSED GLAZE IN GMS. PER SQ. CM.
FIG. I.
GLAZE II
56% Moisture
72% "
83% "
110% "
PERCENT POROSITY
WT. OF FUSED GLAZE IN GMS. PER SQ. CM.
HUNT
GLAZE III
60% Moisture
78% "
92% "
125% "
PERCENT POROSITY
WT. OF FUSED GLAZE IN GMS. PER SQ. CM.


TRANS. AM. CER. SOC. VOL. XIX
GLAZE I
Porosity Range 29.31 to 30.65 %
" " 27.75 to 28.50 %
" " 21.21 to 22.61 %
" " 14.53 to 15.74 %
PERCENT MOISTURE
WT. OF FUSED GLAZE, GMS. PER SQ. CM.
FIG. 2
GLAZE II
Porosity Range 28.39 to 30.03 %
" " 26.45 to 27.23 %
" " 21.40 to 22.20 %
" " 15.05 to 15.66 %
PERCENT MOISTURE
WT. OF FUSED GLAZE, GMS. PER SQ. CM.
HUNT
GLAZE III
Porosity Range 28.30 to 31.41 %
" " 26.28 to 27.35 %
" " 20.96 to 22.80 %
" " 15.57 to 17.01 %
PERCENT MOISTURE
WT. OF FUSED GLAZE, GMS. PER SQ. CM.

The attempt to regulate the amount of glaze by estimating the thickness of glaze to one-eighth or one-tenth of an inch is not sufficiently accurate to secure uniform results, where the porosity of the body varies.

Uniform results may be expected over a fairly wide range of porosity, if the weight of glaze per unit area is controlled.

Acknowledgment is made to Mr. F. W. Walker, Jr., and Mr. E. G. Kerr for the use of the trials and data from their experiments.

TABLE I — DATA — GLAZE I.

		A	B	C	D	E	F	G	H
	a	65	69	76	81	88	92	104	105
1	b.	30.65	29.78	29.70	30.60	30.59	30.35	29.31	29.75
	c.	.342	.199	.183	.168	.156	.169	.161	.109
2	b.	28.39	28.50	27.90	27.95	28.00	28.31	27.75	28.00
	c.	.256	.168	.173	.163	.139	.155	.143	.108
3	b.	26.72	27.25	27.19	26.89	27.62	27.00	27.49	27.10
	c.	.274	.181	.156	.136	.136	.151	.153	.160
4	b.	25.50	24.21	25.39	24.59	24.90	25.80	24.70	24.00
	c.	.253	.160	.149	.107	.118	.112	.119	.132
5	b.	23.82	23.90	23.69	23.29	23.71	23.98	23.40	23 55
	c.	.201	.154	.133	.106	.112	.114	.125	.123
6	b.	21.83	21.6	21.50	22.20	21.21	22.61	22.00	22.00
	c.	.197	.137	.125	.108	.101	.131	.124	.116
7	b.	20.80	20.4	20.80	19.40	20.40	19.95	19.58	20.65
	c.	.152	.136	.097	.135	.105	.078	.078	.105
8	b.	18.37	18.02	17.73	19.19	19.14	19.39	18.65	19.20
	c.	.175	.115	.113	.081	.069	.090	.079	.076
9	b.	17.48	17.76	17.11	16.94	16.88	16.74	17.16	17.03
	c.	.162	.105	.164	.074	.069	.072	.081	.076
10	b.	14.73	14.53	14.54	15.59	14.90	15.15	15.74	15.70
	c.	.162	.092	.072	.070	.062	.061	.065	.069

a = Moisture content of glaze in percent of the dry weight.
b = Percent porosity of the body.
c = Weight of fused glaze in grams per sq. cm. of tile surface.

TABLE II — DATA — GLAZE II.

		A	B	C	D	E	F	G	H
	a	56	65	72	80	83	91	100	110
1	b.	30.70	29.15	29.98	28.60	28.39	30.39	29.65	29.02
	c.	.305	.251	.182	.165	.141	.163	.175	.184
2	b.	28.81	27.82	28.48	28.21	28.30	28.25	28.25	28.72
	c.	.241	.192	.204	.184	.137	.171	.177	.170
3	b.	27.25	27.25	27.35	27.00	26.45	26.61	26.85	26.61
	c.	.260	.209	.195	.161	.152	.162	.141	.146
4	b.	24.05	24.05	24.05	25.00	25.05	25.25	24.45	25.32
	c.	.245	.170	.133	.128	.125	.143	.134	.145
5	b.	23.75	23.48	23.05	23.60	23.65	23.64	22.52	22.78
	c.	.222	.154	.130	.116	.137	.142	.115	.106
6	b.	21.80	21.40	21.60	22.20	21.70	21.60	21.65	21.46
	c.	.216	.191	.127	.117	.132	.126	.146	.115
7	b.	20.70	20.75	21.00	20.90	20.75	20.78	20.65	20.55
	c.	.177	.123	.095	.077	.117	.103	.115	.085
8	b.	18.18	19.50	19.27	18.90	18.55	18.90	19.03	18.60
	c.	.145	.138	.078	.105	.109	.098	.097	.086
9	b.	17.70	17.55	17.24	17.36	17.00	16.99	17.57	17.73
	c.	.203	.122	.081	.097	.105	.096	.115	.107
10	b.	15.50	15.35	16.02	15.20	15.05	15.13	15.66	15.51
	c.	.150	.080	.077	.088	.087	.068	.086	.080

a = Moisture content of glaze in percent of the dry weight.
b = Percent porosity of the body.
c = Weight of fused glaze in grams per sq. cm. of tile surface.

TABLE III — DATA — GLAZE III.

		A	B	C	D	E	F	G	H
	a	60	69	78	88	92	97	111	12_5
1	b.	28.89	31.41	29.75	29.30	30.55	30.10	29.79	28.50
	c.	.250	.232	.142	.148	.181	.163	.149	.155
2	b.	27.75	27.80	27.95	27.72	27.75	27.70	27.58	27.65
	c.	.242	.170	.181	.131	.130	.153	.140	.136
3	b.	26.48	27.35	26.55	26.50	26.28	26.85	26.55	26.52
	c.	.245	.163	.162	.130	.139	.175	.131	.136
4	b.	25.62	24.95	25.90	25.59	25.78	25.65	25.87	25.65
	c.	.224	.161	.163	.113	.147	.173	.129	.131
5	b.	22.98	22.59	22.71	22.95	22.38	22.92	23.38	23.84
	c.	.199	.148	.126	.105	.129	.141	.159	.168
6	b.	21.38	21.18	21.30	21.70	22.70	22.80	22.10	20.96
	c.	.211	.139	.132	.139	.139	.139	.124	.135
7	b.	20.75	20.85	21.00	19.90	20.24	19.87	20.42	20.78
	c.	.134	.111	.101	.134	.097	.104	.142	.121
8	b.	18.51	18.73	18.30	18.90	18.70	19.28	18.98	18.36
	c.	.151	.103	.099	.110	.095	.096	.116	.104
9	b.	17.82	17.51	17.29	17.39	17.17	16.63	16.53	16.75
	c.	.159	.115	.088	.111	.074	.095	.113	.094
10	b.	15.67	15.57	16.28	16.30	17.00	16.48	17.01	16.02
	c.	.142	.088	.072	.100	.066	.112	.093	.096

a = Moisture content of glaze in percent of the dry weight.
b = Percent porosity of the body.
c = Weight of fused glaze in grams per sq. cm. of tile surface.

DISCUSSION

Mr. Pence: I have been very much interested in the presentation of this data. It is simply a technical statement of what is the common experience of tile manufacturers in the application of mat glazes. Where there is a tendency of the mat glaze because of its particular type to crawl or separate or develop these drying cracks, it is the common experience that the heavier or the thicker the glaze is applied upon the tile, the greater

that tendency will be. There are some types of mat glazes which must necessarily be kept thin in order to reduce or avoid this development, while others will heal to a smooth surface even when applied thick. Of course it is also possible to use adhesive agents in the glaze to overcome the tendency.

A STUDY OF THE PHYSICAL AND CHEMICAL PROPERTIES OF THREE COMPOUNDS OF LEAD AND THEIR USE IN RAW LEAD GLAZES

BY F. A. MORGAN.

The fact that litharge or the yellow oxide of lead has been so satisfactory as a source of lead for glass, enamels and frits suggested that it could also be used in raw lead glazes.

The fact that it had long been used by the manufacturers of yellow ware tended to prove that it was entirely satisfactory in the dipping tub, and work done on its more extensive use proves the resulting glazes to be identical with those from white lead.

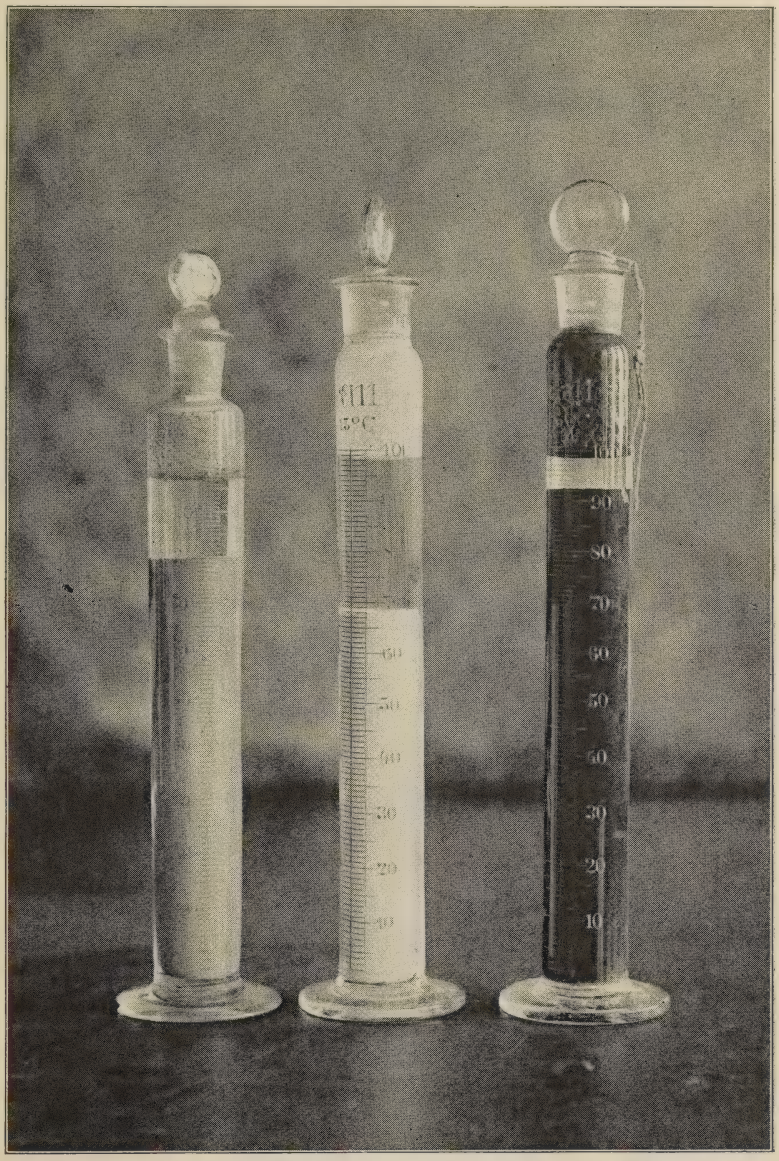
In Vol. XVII of the transactions in a paper on "Lead Oxide Versus Lead Carbonate" Professor Watts pointed out the saving effected by the use of the oxides owing to their greater content of lead oxide. The use of the oxide offers an economy which cannot be overlooked by the users of raw lead glazes. The following table illustrates this point:

	PbO	BALANCE	COST OF 100 POUNDS	COST OF 100 POUNDS PBO
	percent			
Yellow lead.	100.00	None	$10.00	$10.00
Red lead....	97.66	2.34 percent Oxygen	10.50	10.75
White lead..	86.30	13.7 percent CO_2 and H_2O	9.25	10.70

Prof. Watts found the resulting glazes practically the same whether the oxides or white lead was used.

In the discussion that followed several doubtful points were brought out, and on these specific information has been obtained. Among these doubtful points were the relative settling or suspension properties, purity, fluxing and volatilization.

The fumed oxides were compared with white lead and the most important physical and chemical properties were:


90
80
70
60
50
40
30
20
10

PHYSICAL:	SPECIFIC GR.	WT. PER CU. IN. SCOTT VOLUMETER	THRU 200 MESH.	SETTLING
			percent	
Fumed yellow oxide.	8.98	11 gm	98.63	20
Fumed red oxide....	8.52	10 gm	98.99	8
White lead	7.14	17.5 gm	98.32	32

CHEMICAL:	METALLIC LEAD	COPPER	IRON	SULPHUR	CARBON	SiO_2
Fumed yellow oxide...	Trace	0.002	0.005	Trace	Trace	0.14
Fumed red oxide.....	None	0.002	0.005	Trace	None	0.16
White lead	0.15%	0.0018	0.004	None	Trace	0.12

The weight per cubic inch was obtained by Scott's volumeter and is an approximate measure of fineness; the lower the weight per cubic inch the finer the material. Thus altho the white lead has a lower specific gravity, it weights more per cubic inch, which shows it is not so finely divided as the oxides:

The settling numbers above refer to the number of cc. each had settled when suspended in water in a 100 cc. graduated cylinder. This is shown by Figure 1.

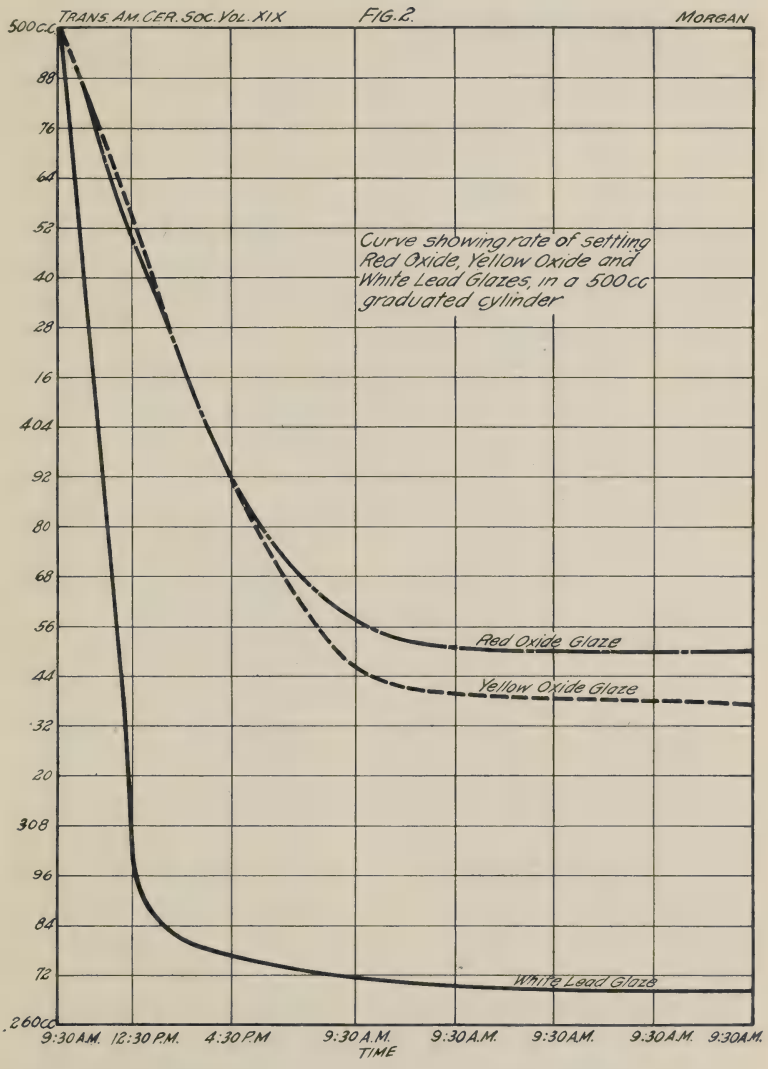
The following glaze given by Professor Watts was made up by using the three products in the proportion of PbO content:

Soft Raw Lead Glaze:

$$\left.\begin{matrix} 0.60\ PbO \\ 0.10\ K_2O \\ 0.15\ CaO \\ 0.15\ ZnO \end{matrix}\right\} 0.15\ Al_2O_3 - 1.5\ SiO_2$$

In number one 48.23 parts of yellow oxide were used.
In number two 49.38 parts of red oxide were used.
In number three 55.85 parts of white lead were used.
The balance of the batch was in each case as follows:

Potash feldspar	20.04
Whiting	5.40
Zinc oxide	4.38
China clay	4.65
Flint	17.30


TRANS. AM. CER. SOC. VOL. XIX
FIG. 2.
MORGAN
500 CC
88
76
64
52
40
28
16
404
92
80
68
56
44
32
20
308
96
84
72
260 CC
Curve showing rate of settling Red Oxide, Yellow Oxide and White Lead Glazes, in a 500 cc graduated cylinder
Red Oxide Glaze
Yellow Oxide Glaze
White Lead Glaze
9:30 A.M.
12:30 P.M.
4:30 P.M.
9:30 A.M.
9:30 A.M.
9:30 A.M.
9:30 A.M.
9:30 A.M.
TIME

The following glaze of a specific gravity of 1.5 was produced:

	QUANTITY	SETTLING	VISCOSITY	WEIGHT ADHERING TO TILE
With yellow oxide.....	1190 cc.	30	28 (cc.)	4.00 gm
With red oxide.....	1205 cc.	32	33 (cc.)	3.50 gm
With white lead.....	1230 cc.	205	64 (cc.)	2.40 gm

The greater quantity of the white-lead glaze is accounted for by the additional quantity of white lead necessary (about 14 percent more by weight than of the oxide) to get equal amounts of PbO present.

The settling represents the number of cc. of settling in each glaze in a 500 cc. graduated cylinder. This is illustrated by Figures 2 and 3.

The viscosity was obtained by using a standard viscosimeter. The greater viscosity of the oxide glazes was due to the greater fineness of these products. The influence of this factor on the dipping properties of a glaze is shown by the weights of glaze adhering to the tile which otherwise were treated exactly the same.

From this it can be seen that the glazes must be adjusted on a different basis than volume weight. Therefore, the three types of glazes were adjusted to equal viscosity:

	VISCOSITY	SPECIFIC GRAVITY	WEIGHT ADHERING
	cc.		*grams*
Yellow oxide glaze.....	64	1.345	2.2
Red oxide glaze.....	64	1.323	2.1
White lead glaze.....	64	1.50	2.4

This proved a better standard for obtaining like-dipping results than the volume weight standard.

A series of tile were dipped and fired, withdrawals being made at 440°C. and 840°C. to observe the action before fusion.

At 440° the white lead glaze was not distinguishable from the yellow oxide glaze, for the former glaze had turned to a yellow color showing complete dissociation of the white lead into carbon dioxide gas, water and the yellow oxide. The red oxide glaze was apparently unchanged.

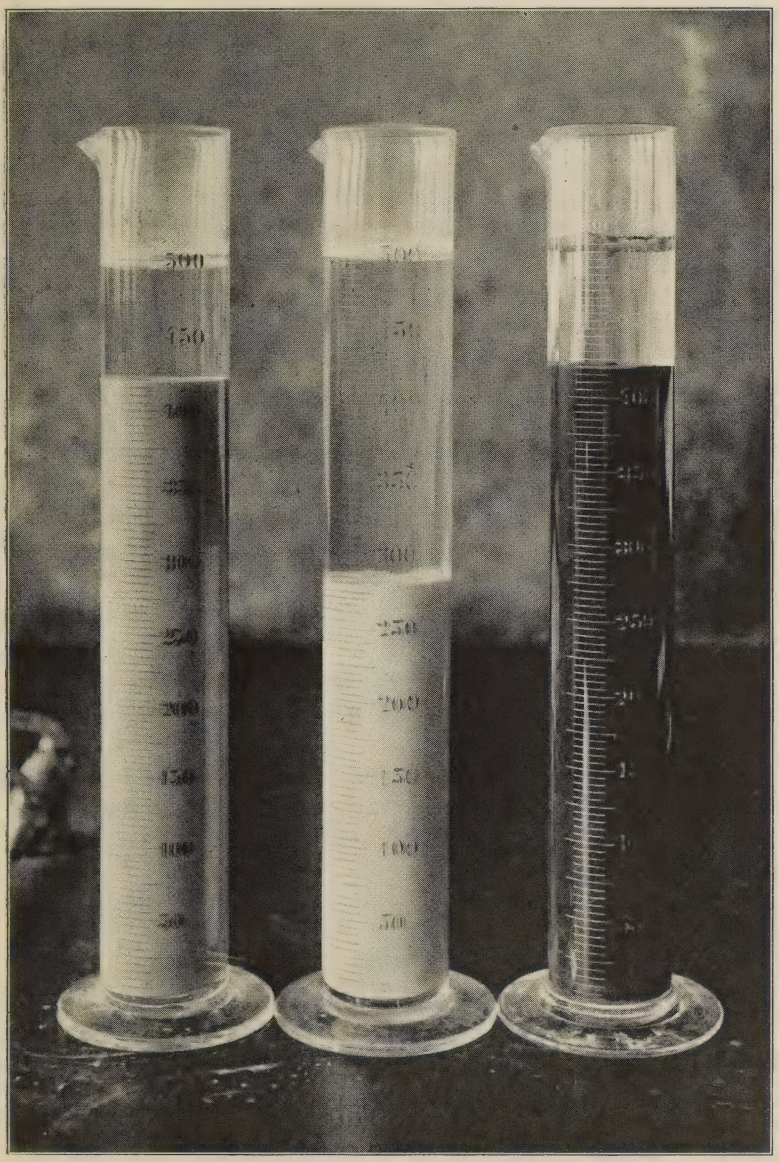


FIG. 3.

To ascertain the exact temperature of the above dissociation of the white lead, determinations were made and this point established at 420°C.

From 420° on it was assumed the action would be identical as the glazes had now virtually become equivalent.

At 840° the glazes were evidently in the midst of the boiling period, for when withdrawn and cooled, the glazes had the appearance of hardened foam; being very porous and presenting a very uneven surface.

Series of tile were weighed before and after firing, and showed the following losses: —

	percent
Yellow oxide glaze	4.7
Red oxide glaze	5.0
White lead glaze	10.0

This loss is percent of weight of dry glaze lost during firing to cone 02. It represents not only volatilization, but loss from dehydration and escape of gases.

From the foregoing study, it was concluded:

That the oxides are equal in purity to white lead.

That altho the fumed oxides have a higher specific gravity they have greatly superior suspension properties due to their greater fineness.

That in substituting these oxides for white lead, an adjustment is necessary in the viscosity of the glaze.

That in the unfired condition the oxide glazes have a much harder surface, hence they do not dust so badly.

That the oxides effect a saving due to their greater content of lead oxide.

That in the physical behavior of these oxides there is nothing to prevent their substitution for white lead.

That when the oxides are used to replace white lead, the resulting glaze will be the same, provided equivalents of PbO are present.

THE DEVELOPMENT OF CERAMIC DECORATIVE PROCESSES

BY FREDERICK H. RHEAD

The development of ceramic decorative processes is a subject almost entirely neglected by present-day ceramists. Such neglect is not due to the non-progressiveness of the scientifically inclined potter, nor to lack of skilled craftsmen. The fact is, the field of the ceramist is such a vast one that it is impossible to conceive of its being covered even in the most elementary fashion in a thousand years from now. In the four thousand years or so in which the potter has been quite active, enough has been accomplished to show the possibilities yet to be realized when the present trend towards scientific research has seriously commenced to bear fruit.

The development of any art is a curious phenomenon. It is so personal and human. There is little that is consistent or mechanical or even scientific about it. There is no formula for art, it cannot be manufactured. It is of no country nor nationality. It appears, spontaneously to all peoples, reaches a high degree of development and declines.

In ceramic work, from the very first manipulations in plastic earth and their subjection to crudely applied heat to the present day processes where scores of elaborately prepared materials are used in a great variety of ways, the type of ware produced by the potter has been limited not so much by his skill or ingenuity as by his available natural resources, his supplies of earths for bodies, and of metals, quartzes and alkalies for stains and glazes.

The discovery of the plastic properties of clay led to the production of molded forms which were developed and decorated according to the known means at hand. The color of the clay determined the color of the finished product. In the beginning, there was no choice of materials or process. The shapes were regulated by the needs of the primitives; the dec-

orations were their whimsical conceptions of the sun, moon, stars, natural forms and motifs symbolical of their fears or superstitions. The methods of depicting such ornamentation were very definitely determined by the means at hand. When the clay of which the pot was made was the only available material, the decoration was scratched on the surface with a stick, or crudely modeled. When other colored clays were discovered, these were used as stains for ornamentation, alone, as painting, and together with the incised or relief decorations. This was the first step in the development of the decorative processes.

It is very definite that the primitive potteries of all countries were identical in process and arrangement of decoration. The only difference in appearance was due to the color of clay used, and the type of heat applied.

It is only when the materials peculiar to each country are discovered and used that the technique and methods of the potter begin to vary and definite historical types are established.

The Chinese discovered and developed their porcelain clays. The Italians discovered first the terra-cottas (elaborations of the early clay processes) and later their tin enamel processes. The Europeans developed the white earthenwares, and the stoneware (coarse opaque earthenware) using lead and salt glazes. As each country became familiar with the work of the others, learning of new materials, and strange and wonderful results, search was made for these materials, and when they could not be found, the effects desired were obtained in other ways. Those countries that were most successful in the development of the art influenced the potters of other countries, not only in process but in style of decoration. When the Europeans could not find kaolins, and were consequently unable to make porcelains, they covered their coarse earthenware clays with white opaque enamel, painting actual copies or imitations of Chinese decorations over this. With the exception of the Italian painted decorations, the Oriental influence practically dominated the European potter. From time to time, however, the natural decorative instinct of the peasant potter

would assert itself, and the influence of native artists would be felt and expressed.

The potters, drawn by the fascinations and inspired by the possibilities of the work, discovered new materials, and developed and elaborated the methods and processes, but the development has never been continuous nor consistent. All the great historical types have been produced within a comparatively short period, appearing, reaching the highest point of development and declining within from one hundred to four hundred years.

In modern work, the commercial spirit has gradually taken possession, and now dominates the production. The artist potter is almost eliminated, replaced by the scientist engaged in research who is studying, analyzing and standardizing available materials and methods. It was necessary and inevitable that the scientist should take the helm. The artist had elaborated the processes until he was no longer master of his medium.

Today the technical societies are the strongest force working for the benefit of the ceramist, but they are working independently, and almost to the complete isolation of the artist and even the practical potter. In ceramics, science is entitled to neither first nor second place. The mechanical brain of the potter, the common sense of the artist and the practical man have developed the field. But the scientist, in coming to the rescue of the craftsman, has become absorbed in his problems, and he has forgotten that it is the craftsman who has shown him the possibilities of the work, and he is apparently oblivious of the fact that, unless he works in co-operation with the artist, there can be no further development of the art.

These remarks are made advisedly, with some knowledge of past and present conditions, but with no reference to any particular field of work. While the technical societies are the most highly developed ceramic organizations, they are at present little more than associations of earnest and sincere workers engaged in cosmopolitan and disconnected research for the benefit of each other rather than for the enlightenment and convenience of the artist and practical potter.

Compare such organizations with a society composed of committees, each one dealing systematically, consistently, and individually with such problems as kiln construction, fuels, kiln temperatures and atmospheric conditions, porcelain clays, opaque clays, refractories, stains, glazes and enamels, to crudely specify a few general branches of the work. When one considers the vastness of such an undertaking, and then realizes that the decorative and practical processes have yet to be dealt with, the imagination balks at the possible existence of an organization adequately dealing with the subject.

It is inevitable that the scientist take in the artist, if the possibilities are to be further realized, if we are to engage the co-operation of the craftsman of note. It is not in the least essential that an artist interested in ceramics should take a four years' course in ceramic engineering before he is able to execute a decorative panel, a frieze in underglaze colors over tin enamel, or a figure subject in colored slips, but it is essential that the processes be scientifically arranged and prepared. On rare occasions an artist has appeared who has mastered his particular processes. The difficulties he encountered in overcoming the most elementary obstacles are well enough known to every ceramist.

We have one American potter, Mrs. Robineau, who has produced works which rank with any other pottery of any period. The inspiration for her work was a book on porcelain making by Taxile Doat of Sevres. If this book had been written in technical language for technical people, the Robineau porcelains would never have appeared. The influence resulting from a practical and understandable exposition of the technical man's work, and his co-operation with the artist needs no further discussion here. We have the best technical and scientific minds in the country engaged in ceramic work while artistically the modern pottery is a nonentity.

A DEFORMATION STUDY OF $MgO - Al_2O_3 - SiO_2$ MIXTURES

BY ARTHUR S. WATTS

The work presented last year showed the possibility of lowering the temperature of maturity of Bristol glaze mixtures much below that at which they are ordinarily used. The practice of confining the Bristol glaze fluxes to K_2O, CaO and ZnO is almost universal. There are, however, other alkaline earth fluxes which properly belong to this class of glazes and chief among these are magnesium oxide and barium oxide. These fluxes have been employed in small quantity in porcelain glazes and have made a marked improvement in the product. The chief reason for not introducing them into lower-fire glazes was the fact that their fusion temperature in Al_2O_3-SiO_2 mixtures has been considered too high to make their use practical. The most fusible ZnO-Al_2O_3-SiO_2 mixture was found to deform at cone 13, and this mixture was very active as a third component in lowering the temperature of fusion of K_2O-CaO-Al_2O_3-SiO_2 mixtures. It was, therefore, considered advisable to investigate the deformation temperature of other aluminium silicate mixtures. Every glaze maker knows that with increase in the number of bases introduced, a rapid decrease in viscosity and temperature of fusion is apparent. For this reason nearly every commercial glaze contains exceedingly small amounts of one or more fluxes, the quantity added being apparently negligible but claimed by the maker to be very potent in improving the product. The question arises whether it is possible to improve our Bristol glaze, or lower its maturing temperature, or increase its range of adaptability, by adding other aluminium silicates than those ordinarily employed but without entering the field of bases belonging to the very soft glazes. With this end in view, the following investigation was undertaken. The object first sought was the most fusible mixture of MgO-Al_2O_3-

SiO_2 using as the sources of these elements $MgCO_3$, kaolin and flint.

The $MgCO_3$ and flint were practically pure. The Al_2O_3 was introduced as English china clay having the following chemical composition:

Comb.	H_2O	13.30
	SiO_2	46.52
	Al_2O_3	38.40
	Fe_2O_3	0.21
	TiO_2	0.04
	CaO	trace
	MgO	trace
	KNaO	1.36
		99.83

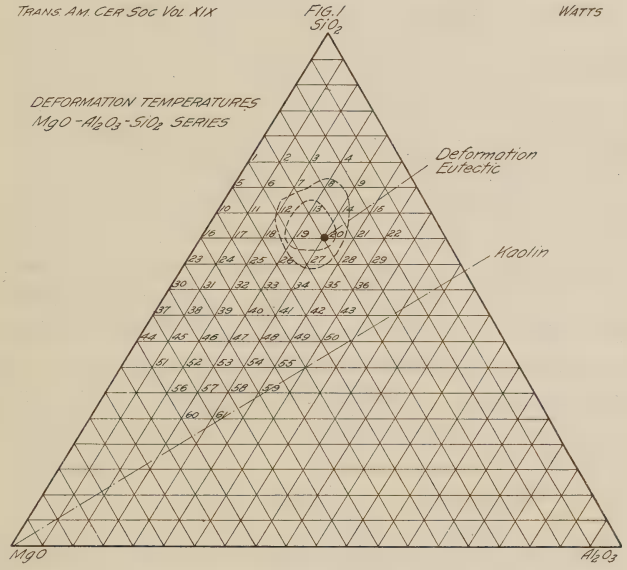
The object being to confine our study to mixtures containing Al_2O_3 introduced from kaolin, the series was limited by the Al_2O_3-SiO_2 ratio occurring in kaolin, and that proportion is indicated upon the triaxial diagram representing the series studied.

The mixtures indicated were thoroly mixed in plastic form to a state of thoro homogeneity and made into cones of the same size as standard pyrometric cones. The addition of a little dextrine was resorted to as those mixtures high in $MgCO_3$ are very weak even tho containing some clay.

The cones were placed in plaques containing about ten each, and standard pyrometric cones and a recording pyrometer were used to check temperature and the rate of temperature increase. The burn was conducted in a horizontal draft, gas-fired kiln equipped with a brick muffle to protect the test cones from direct contact with the flames, and combustion gases.

The Burn. A rise in temperature of about 75° C. per hour was maintained until about 1150° C. was reached. The rate of increase was then reduced to about 40° C. per hour until 1300° C. was reached. Above this the rate of increase was about 20° per hour.

Results. At cone 8 down, those mixtures containing 40 percent or less SiO_2 began to curl forward, and this was at first mistaken for deformation. After they had deformed about one-third, however, they showed no tendency to progress further. When cone 10 temperature was reached a pronounced shrinking of certain members of the series was noticed, and by consulting the triaxial diagram these were found to be within the following general limits: 35 percent or more MgO, 10 percent or more Al_2O_3, and 30 percent or more SiO_2. As



the temperature increased, the shrinkage increased until the cones containing 45 percent or more MgO were less than one-half their original size. At the temperature of cone 13 started, the burn was stopped and the kiln allowed to cool. The mixtures containing 5 to 15 percent Al_2O_3, 35 to 50 percent MgO and 45 to 60 percent SiO_2 were found to be highly translucent and to show no trace of warping. The range of compositions showing the greatest translucency is traced in Fig. 1 upon connecting numbers 17, 25, 48 and 45.

Another burn was conducted to determine the order of deformation of the mixtures. The process was the same as in the previous burn. When cone 12 was just down, mixture No. 20 deformed very rapidly. It has the composition 20 percent MgO-20 percent Al_2O_3-60 percent SiO_2 — MgO-.392 Al_2O_3-2.0 SiO_2. A slight increase of temperature caused the deformation of mixture No. 19 having the composition 25 MgO-15 Al_2O_2-60 SiO_2. Almost at the same temperature, deformation occurred in mixture No. 13, having a composition 20 MgO-15 Al_2O_3-65 SiO_2. All these mixtures mentioned deform after cone 12 and before cone 13 starts. With the first evidence of fusion of cone 13, the following mixtures begin to deform, and their deformation is complete before cone 13 is half down.

Mixture No. 8 — 15 MgO — 15 Al_2O_3 — 70 SiO_2
Mixture No. 12 — 25 MgO — 10 Al_2O_3 — 65 SiO_2
Mixture No. 14 — 15 MgO — 20 Al_2O_3 — 65 SiO_2
Mixture No. 27 — 25 MgO — 20 Al_2O_3 — 55 SiO_2

Conclusions. The most fusible mixture of MgO — Al_2O_3 and SiO_2 as indicated by the foregoing study is as follows: 20 percent MgO-20 percent Al_2O_3-60 percent SiO_2 — MgO-.392 Al_2O_3-2.0 SiO_2. Deformation temperature is cone 12 down, cone 13 not started. The deformation process is very rapid.

A DEFORMATION STUDY OF $BaO - Al_2O_3 - SiO_2$ MIXTURES

BY ARTHUR S. WATTS

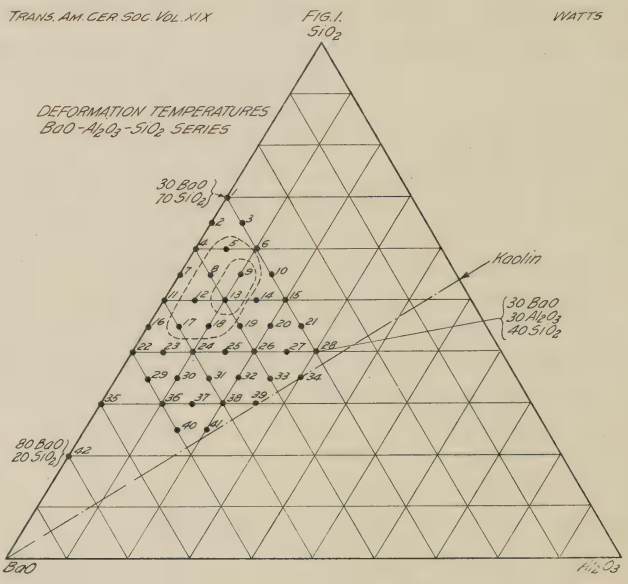
Continuing the search for those deformation eutectics which may enter into Bristol glazes, a series of mixtures was compounded of $BaCO_3$, kaolin and flint. The accompanying triaxial diagram shows the range of composition studied. The Al_2O_3 content was confined to that which could be introduced from kaolin. English china clay was used for this purpose, and is the same as that used in the $MgO - Al_2O_3 - SiO_2$ study.

Each mixture was mixed thoroly together in the plastic state and molded into cones of the same unburned size as the standard pyrometric cones. The use of a small amount of dextrine was resorted to when the clay content was not sufficient to produce the necessary plasticity. The cones were placed in plaques of ten each, and standard pyrometric cones were placed along both ends as guides. A recording pyrometer was also employed as an additional check. The burn was conducted in a horizontal draft, gas-fired kiln, a brick muffle being constructed in the chamber to protect the cones. The temperature was regulated so that a very uniform heat distribution was secured throughout.

The Burn. The heat was increased at about a rate of 75° C. per hour for the first fifteen hours. Beyond the fifteenth hour, a rate of about 40° C. per hour was maintained until the first mixture showed signs of deforming when the temperature increase was reduced to about 20° C. per hour.

Results. When a temperature slightly above 1230° C. was reached and cone 6 was starting, the mixture No. 13 (40 percent BaO, 10 percent Al_2O_3, 50 percent SiO_2 — BaO, .375 Al_2O_3, 3.19 SiO_2) began to deform. With 10° C. rise in temperature and before cone 6 was down, mixture No. 9 (35 percent BaO, 10 percent Al_2O_3, 55 percent SiO_2 — BaO, .42 Al_2O_3, 4.0 SiO_2) also started. The viscosity of mixture No. 9 was so

low that it overtook mixture No. 13 in the deformation process, and standard cone 6, mixture No. 13 and mixture No. 9 all reached at the same time the state of deformation where the point of the cone reaches the level of the base. The more rapid deformation of mixture No. 9, however, would indicate that it is the deformation eutectic even though it did not start deformation first. About the time mixtures Nos. 9 and 13 completed deformation, mixtures Nos. 5, 8, 12, 17 and 18 began to deform, and before they had completed deformation which was approxi-



mately with cone 7, members Nos. 6, 23, 24, 29 and 30 began to deform. These were followed by mixtures Nos. 10, 14, 19, 25 and 31, which deformed at about the temperature of cone 8. The mixtures Nos. 3, 20, 26, 32, 36, 37 and 40 deformed with cone 9, member No. 40 showing abnormally rapid deformation. The study has not as yet been carried beyond the temperature at which cone 10 starts, which is approximately 1330° C. At this temperature, mixtures Nos. 27, 38, 39 and 41 show first evidences of deformation.

Up to this temperature, no mixture of BaO and SiO_2, alone has deformed and none is vitrified. The members containing no Al_2O_3 and 55 percent or more BaO, show a tendency to crack badly on burning, and several broke completely apart. All the numbers containing 5 percent Al_2O_3 show a marked opacity. The members containing 10 percent Al_2O_3 are either clear or show a tendency toward forming clear glasses. The members containing 15 percent Al_2O_3, all give evidence of a highly viscous surface coating with more fluid material inside. This would point toward volatilization in these numbers which did not begin to deform until cone 8 temperature was reached.

Conclusion. Within the limits of the foregoing study it is shown that either member No. 9 (35 percent BaO, 10 percent Al_2O_3, 55 percent SiO_2) or member No. 13 (40 percent BaO, 10 percent Al_2O_3, 50 percent SiO_2) is the deformation eutectic, and both deform completely at cone 6 down. The choice depends upon the state of deformation which is taken as the finishing point.

THE RELATION OF SALT TO CLAY IN THE PURIFICATION OF CLAYS[1]

BY H. G. SCHURECHT.

This paper deals with the effect of alkalies on the viscosity of clay suspensions (slips), with special reference to the relation between the concentration of alkalies necessary to produce minimum viscosity in clay slips and the concentration of clay in the same. A knowledge of this is of fundamental importance not only in the purification of clays but also in the casting of clay wares. The limits within which the slips can be successfully used in the purification and casting processes are often relatively narrow and any erroneous additions of alkalies to these would cause serious trouble.

Statistics[2] show that the total clays or earths imported into the United States during the twelve months ending June, 1916, amounted to 288,235 tons valued at $1,705,995. This compared with the 345,419 tons valued at $2,246,807 which were imported into this country during the twelve months ending June, 1914, shows a large decrease due chiefly to the European war. In many cases manufacturers of this country have been forced to rely upon domestic clays to take the place of those previously imported from Europe. Many domestic clays which are too impure to be used in the crude state can be utilized by purifying. In order, however, to improve the quality and uniformity of the product and increase the output in the purification of clays with alkalies, it is necessary to maintain minimum viscosity in the clay slip during certain stages of the treatment. This is governed by the quantity of alkalies added to the slip.

The correct additions of alkalies to the casting slip is essential in the casting of clay wares. The casting of heavy wares is not practiced nearly as extensively in this country as

[1] By permission of the Director of the U. S. Bureau of Mines.

[2] *Monthly Summary of the Foreign Commerce of the United States*: Bureau of Foreign and Domestic Commerce, June, 1916, p. 6.

it is in Europe. For instance, the casting of glass pots and other refractories is being carried on with success in many places in Europe but is not practiced to any great extent in this country, although it is claimed that the cast pots are of better quality, will last longer, and can be made at less cost than hand-made pots.

Previous Work. The effect of acids, alkalies and salts on clay slips has been investigated by many, but little work has been done to show whether the ratio of electrolyte to clay in slips or the concentration of the electrolyte is the predominating factor in determining how much alkali should be added, where the water and the clay contents vary. Böttcher[3] determined the effect of alkalies on the viscosity of clay slips containing about 44 percent clay and 56 percent distilled water. He diluted portions of each slip thus treated until they contained about 4 percent clay and 96 percent water, and his results show that minimum viscosity in the high clay slips corresponds approximately to maximum deflocculation in the high water slips. This would indicate that the ratio of electrolyte to clay is more important than the ratio of electrolyte to water in the slip in determining how much alkali should be added, because changing the ratio of electrolyte to water and keeping the ratio of alkali to clay constant did not change the point of maximum deflocculation to any great extent. This is in agreement with results obtained in this paper.

Ashley[4] using 0.1 molar sodium oxalate, the total volume always being 100 cc. gives the following results:

WEIGHT OF CLAY	AMOUNT OF REAGENT GIVING MAXIMUM SUSPENSION	AMOUNT OF REAGENT PER GRAM OF CLAY
grams	*cc.*	*cc.*
20	60	3.0
5	13	2.6
1	11	11.0
0.1	11	110.0

From this it appears that in the high clay slips the predominating factor is the ratio of electrolyte to clay; but in

[3] Böttcher, M., Ueber die Verflüssigung des Tones durch Alkali: *Sprechsaal, Jahrg. 42*, 1909, p. 169.

[4] Ashley, H. E., Technical Control of the Colloidal Matter of Clays: *Bureau of Standards Technical Paper 28*, 1913, pp. 45-46.

the high water slips the ratio of electrolyte to the water becomes the important factor. The high water slips here given, however, contain a less percentage of clay than those ordinarily used. The work in this paper deals only with slips containing more than five percent clay.

The following paragraph is taken from McDougal's work.[5]

"The curves, which show that maximum thinning, indicating maximum conversion of gel to sol, is effected by adding the same quantity of carbonate per 500 cc. regardless of the different amounts of clay in suspension, indicate that the effect produced is dependent upon the concentration of the carbonate in the water present. Curve 3 indicates a maximum point with somewhat lesser additions than in the case of curves 1 and 2, which can be explained by the fact that slip 3 contained more solid material and consequently less water (in 500 cc. of slip), and, therefore, the concentration required for maximum effect was sooner reached."

It appears, therefore, that the data published by the different investigators is not consistent, some claiming that the electrolyte should be added in terms of water regardless of the amount of clay in the slip, while others claim that in certain cases the electrolyte should be added in terms of clay in the slip regardless of the amount of water present.

EQUILIBRIUM IN ELECTROLYTES[6]

Electrical Conductivity. The specific resistance of an electrolyte may be defined as the resistance in ohms of a cm.^{3} of an electrolyte. Its specific conductivity would then be 1 ÷ specific resistance, expressed in reciprocal ohms. In studying the effect of dilution on the electrical conductivity it is more convenient to use the molecular conductivity also called the equivalent conductivity. This is the conductivity in reciprocal ohms of a solution containing 1 mol of solute when placed be-

[5] McDougal, T. G., The Casting of Clay Wares: *Bureau of Mines Technical Paper 126*, 1916, p. 13.

[6] For fuller details on this subject see Senter, G., *Outlines of Physical Chemistry*, London, D. Van Nostrand Co., 1916, pp. 234-312; Talbot, H., and Blanchard, A., *Electrolytic Dissociation Theory*, New York, Macmillan Co., 1907, 82 pp; Kahlenberg, L., The Theory of Electrolytic Dissociation in the Light of Facts Recently Ascertained; *Journal of Physical Chemistry, Vol. 5*, 1901, pp. 339-400.

tween electrodes 1 cm. apart. It may also be defined as the specific conductivity multiplied by the volume in cc. which contains a mol of solute.

It is a well known fact that the degree of ionization, hence the molecular conductivity, increases with dilution. Chemical activity increases as a rule with increased electrical conductivity but, it was claimed by Sammis[7] that there is no constant relation between the two. We learn in inorganic chemistry that many reactions proceed wholly or partially in a particular direction for two main reasons: (1) because an insoluble or partly insoluble product is formed which is removed from the reacting system, (2) because a volatile product is formed which under the conditions of the experiment leaves the reacting system. Such reactions are not reliable for determining the strengths of reagents.

For so-called "strong" acids and bases the molecular conductivity increases with dilution up to 1/10,000 molar solution, and beyond this point it remains practically constant on further dilution. At this point the molecules are completely ionized. Table I shows the effect of dilution on the molecular conductivity of some electrolytes. In ceramic practice the normal concentration of electrolyte in water is usually between 0.025 and 0.001. Within these limits it is seen that the change in conductivity for "strong" bases and acids is relatively small while the change in conductivities for the "weak" reagents is large.

The Dilution Law. According to the electrolytic dissociation theory, an aqueous solution of acetic acid contains molecules of non-ionized acid in equilibrium with its ions, represented by the equation

$$CH_2COO + H = CH_3COOH$$

Suppose in the volume v of the solution the total concentration of acid is 1, and that a fraction of it, represented by a, is split up into ions. The concentration of the undissociated acid is $\frac{1 - a}{v}$ The concentration of each of the ions is

[7] Sammis, J. L., On the Relation of Chemical Activity to Electrical Conductivity: *Journal of Physical Chemistry, Vol. 10*, 1906, pp. 593-625.

$\frac{a}{v}$, since the dissociated ions are present in the equivalent amounts. By applying the law of mass action we get the following

$$\frac{a^2}{v} = K \frac{1-a}{v} \quad \text{or} \quad \frac{a^2}{(1-a)v} = K$$

This is known as Ostwald's dilution law; K being the constant of equilibrium. For conductivity measurements, the above formula may be put in a different form by substituting $\frac{Uv}{V\infty}$ for a

$$\frac{u^2 v}{u\infty\ (u\infty - uv)} = K$$

Uv is the molecular conductivity at volume v *and* $u\ \infty$ is the molecular conductivity at the volume where it has reached its maximum conductivity. When the degree of dissociation is small as in the case of acetic acid for fairly concentrated solutions, a can be neglected in comparison with 1, and the dilution law becomes

$$a = \sqrt{Kv}$$

TABLE I — MOLECULAR CONDUCTIVITY AT 18° C.[8]

NORMAL CONCENT'N	NaOH	KOH	$\frac{1}{2}Na_2CO_3$	NH_4OH	$\frac{1}{2}H_2SO_4$	HCL	HNO_3
0.0001	....	....	....	66	....	....	.....
0.0002	....	....	....	53	....	....	....
0.0005	....	....	....	38	368	....	....
0.001	208	234	112.0	28.0	361	377	375
0.002	206	233	108.5	20.6	351	376	374
0.005	203	230	102.5	13.2	330	373	371
0.01	200	228	96.2	9.6	308	370	368
0.02	197	225	89.5	7.1	286	367	364
0.05	190	219	80.3	4.6	253	360	357
0.1	183	213	72.9	3.3	225	351	350
0.2	178	206	65.9	2.3	214	342	340
0.5	172	197	54.5	1.35	205	327	324
1	160	184	45.5	0.89	198	301	310
2	131.4	160.8	34.5	0.532	183	254	258

[8] This table of Kohlrausch and Holborn was taken from Senter, G., *op. cit.*, p. 420.

For weak electrolytes the degree of dissociation is approximately proportional to the square root of the dilution.

The dilution law holds only for binary electrolytes *i. e.* electrolytes which split up into two ions only. It holds for nearly all organic acids and bases, but does not hold for salts, or for certain mineral acids and bases. It does not hold for highly dissociated electrolytes, and the values of K calculated for such diminish with dilution. Van't Hoff has proposed the following empirical formula which is fairly accurate for the majority of strong electrolytes:

$$\frac{a^3}{(1-a)^2 v} K_1$$

By substituting a value for a from conductivity or osmotic pressure observations at any dilution v, the equilibrium constant K or K_1 can be calculated. The degree of dissociation can then be calculated from the above formulas for any dilution. According to the dilution law the degree of dissociation, and hence the chemical activity per unit weight of electrolyte, increases with dilution. For high clay slips we would therefore expect to add more electrolyte per unit weight of clay than in high water slips to produce the same degree of deflocculation, because the concentration of electrolyte in the high clay slips would be relatively high, and therefore the electrolyte would not be as highly ionized as it is in the high-water slips. In some cases this was found to be true in this work but only to a slight degree.

Mixture of Two Electrolytes with a Common Ion. The dissociation of weak acids and bases is greatly reduced by the addition of a salt with an ion common to the acid or base. For example, the equilibrium in a solution of acetic acid is represented by the equation $(H)\ (CH_3COO) = K\ (CH_3COOH)$. If sodium acetate is added, the concentration of the acetate ion is largely increased, but the hydrogen ion concentration must diminish because the undissociated acid cannot be changed very much since nearly all of the acid was present in the undissociated form originally. In exactly the same way, the degree of dissociation of ammonia is greatly reduced by the addition of ammonium salts.

Hydrolysis. It is a well known fact that salts formed of a weak base and a strong acid have an acid reaction, and salts formed of a strong base and a weak acid give an alkaline reaction. As water is slightly ionized according to the equation $H_2O \rightleftarrows H + OH$, it may be regarded as both a weak acid and a weak base at the same time, since H ions and OH ions are present.

When two acids are allowed to act upon the same base, the base distributes itself between the acids according to their activities. The ratio of the activities of two acids is as a rule equal to the ratio of the extent to which they are electrolytically dissociated. The same thing holds true in aqueous solutions of salts, the water, in virtue of its hydrogen ion concentration being regarded as one of the competing acids. In the case of a salt formed from a strong acid and a strong base the effect of the H ion of the water is very small in comparison with the strong acid, and hence the solution gives a neutral reaction. In the case of sodium carbonate the water as an acid is comparable in strength to carbonic acid and there is a distribution of the base between the acid and the water. This is known as hydrolysis and may be represented as follows:

$$Na_2CO_3 + 2H_2O \rightleftarrows 2NaOH + H_2CO_3$$

The proportion of sodium carbonate and sodium hydroxide depend upon the relative strengths of water and carbonic acid. The sodium hydroxide and carbonic acid must be present in equivalent amounts, and since the sodium hydroxide is more highly ionized than the carbonic acid the solution contains an excess of the OH ions and hence is alkaline. The formula in which an acid and a base are present in equivalent proportions may be stated as follows:

$$\frac{x^2}{(1-x)v} = Kh$$

Here x represents the proportion of acid and base formed by hydrolysis from 1 mol of the salt and v is the volume. From this it appears that the degree of hydrolysis represented by x increases with dilution.

In a similar way the OH ion of water competes with the base of a salt formed by a strong acid and a weak base, and the highly dissociated acid thus formed causes the solution to give an acid reaction.

The Solubility Product. In the case of a saturated solution of electrolyte there is equilibrium between the solid salt and the non-ionized salt in solution, the concentration of the non-ionized salt remaining constant at constant temperature. At the same time there is equilibrium in solution between the non-ionized salt and its ions. In the case of silver chloride this may be represented by $Ag + Cl \rightleftarrows AgCl$. From the law of mass action we get the following:

$$(Ag)\ (Cl) = K\ (AgCl) = S$$

Here S is the solubility product and is constant since the right-hand side of the above equation is constant. If the solubility product is exceeded by adding a salt with a common ion, the ions unite to form the undissociated salt until the solubility product is reached. The difference between this equilibrium and those previously considered is that the concentration of the non-ionized salt in solution is constant at constant temperatures. If it is decreased in any way, salt is dissolved till the original value is reached; if it is exceeded, salt falls out of solution till the original value is reached.

EFFECT OF ELECTROLYTES ON CLAYS

When certain alkaline salts are added to clay slips in small quantities the slips become liquefied, and the fine clay particles remain in suspension while the coarser particles settle to the bottom. The separation of this coarser substance from the fine clay also takes place to some extent when no alkalies are used; but in this case a large percentage of fine clay is carried down mechanically with the coarser particles. The use of alkalies in the purification of clays makes possible a sharper separation between the coarse impurities and the fine clay substance.

Förster[9] claims that this action of electrolytes on clays occurs because the negatively charged OH ions repel the similarly

[9] Förster, F., Ueber das Gieszen des Tones: *Chem. Industrie*, 1905, p. 551.

charged clay particles thus causing a liquefaction of the clay slip. Spangenberg[10] claims that the OH ion is absorbed by the clay particles, and the so-charged particles repel each other thus causing the clay slip to become more liquid. When the electrolyte is added beyond a certain amount a re-thickening of the slip takes place. Acids, and most acid salts cause a thickening or flocculation when added to clay slips.

When a slip that has been treated with alkalies is allowed to stand it gradually thickens. Neubert[11] showed that slips containing alkali concentrations less than that required for maximum fluidity, thicken when allowed to stand, while slips, containing more alkali than is required to produce maximum fluidity, become more fluid when allowed to stand. Other factors like temperature, humidity and degree of blunging also affect the viscosity of clap slips.

DESCRIPTION OF WORK

To study the relation between the concentration of electrolyte necessary to produce minimum viscosity in clay slips and the concentration of clay in the same, the salt, clay and water contents were varied by means of a triaxial diagram and viscosity measurements were made with a viscosimeter similar to the one used by Bleininger.[12] The clay after being screened through a 120 mesh screen was dried at 110° C. for 48 hours previous to testing. Distilled water was used in all of this work, and the slips were allowed to stand one hour after they had been made up and then were tested. The temperature of the slips was kept within 5 degrees of 18° C.

The time necessary for 250 cc. of slip to pass through an orifice 3/32 inch was measured with a stop watch. In the high-water slips checks were made by passing the slip through an orifice 1/32 inch. The time necessary for the same amount of water at 18° C. was then measured. The densities of the slip

[12] Bleininger, A. V., Notes on Casting: *Trans. Amer. Cer. Soc., Vol. XVII,* 1915, p. 331.
[11] Neubert, J. K., *op. cit.*, p. 568.
[10] Spangenberg, A., *Zur Erkenntnis des Tongieszens, ihren Einflusz auf die Tonverfluessigung, Dissertation, Darmstadt,* 1910; Neubert, J. K., Die Tonverflüssigung durch Alkali: *Sprechsaal, Jahrg. 46,* 1913, p. 524.

and water were determined, and, by means of the following equation the relative viscosities x were calculated

$$x = \frac{dt}{dwtw}$$

In this equation which is used for calculating relative viscosities for liquids with the Ostwald viscosimeter,[13] d and dw are the densities of the liquid and water respectively, and t and tw are times required for the discharge of equal volumes of liquid and water respectively. Owing to the fact that a clay slip is not an ideal liquid and to the difference in construction of the viscosimeters, this equation is not exactly correct in this case, but for this investigation it is sufficiently accurate.

Materials Studied. Two clays were studied in this work, a kaolin and a ball clay. The kaolin came from Gordon, Georgia, and the ball clay came from Mayfield, Kentucky. Their chemical analyses are as follows:

	GEORGIA KAOLIN	KENTUCKY BALL CLAY
Moisture Loss 105° C.	0.38	1.60
Loss of Ignition	13.63	11.52
SiO_2	44.24	46.87
Al_2O_3	38.06	36.58
Fe_2O_3	1.03	1.14
TiO_2	1.29	0.43
CaO	0.08	0.50
MgO	trace	trace
Na_2O	0.10	trace
K_2O	0.70	1.60
S	0.06	0.06
Total	99.58	100.30

The sodium silicate corresponded to the formula Na_2O 3.1 SiO_2.

[13] Senter, G., *Outlines of Physical Chemistry*, London, D. Van Nostrand Co., 1916, p. 75.

TABLE I — VISCOSITY OF GEORGIA KAOLIN WITH SODIUM HYDROXIDE.

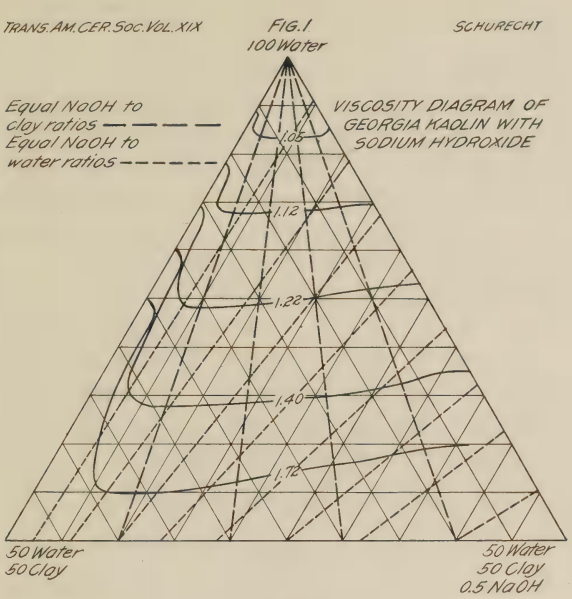
NO.	PERCENTAGE NaOH IN TERMS OF DRY CLAY	5% CLAY 95% WATER	10% CLAY 90% WATER	15% CLAY 85% WATER	20% CLAY 80% WATER	25% CLAY 75% WATER	30% CLAY 70% WATER	40% CLAY 60% WATER	50% CLAY 50% WATER
1	0.00	1.032	1.098	1.199	1.391	1.722	2.587	(a)	(a)
2	0.06	1.032	1.092	1.189	1.323	1.675	1.984	(a)	(a)
3	0.08	1.028	1.066	1.123	1.198	1.250	1.306	1.58	5.87
4	0.10	1.027	1.066	1.112	1.175	1.227	1.306	1.50	2.20
5	0.12	1.028	1.066	1.112	1.163	1.214	1.281	1.49	2.00
6	0.18	1.025	1.066	1.112	1.163	1.214	1.270	1.48	1.93
7	0.26	1.026	1.066	1.113	1.167	1.214	1.263	1.48	1.95
8	0.34	1.025	1.066	1.113	1.165	1.214	1.263	1.50	2.04
9	0.42	1.025	1.065	1.113	1.165	1.214	1.263	1.50	2.10
10	0.50	1.025	1.065	1.113	1.166	1.214	1.269	1.52	2.28
11	0.58	1.025	1.065	1.114	1.166	1.224	1.269	1.53	2.48
12	0.66	1.025	1.064	1.112	1.170	1.224	1.274	1.54	2.81
13	0.74	1.025	1.065	1.113	1.175	1.228	1.276	1.57	3.27
14	0.80	1.025	1.065	1.112	1.175	1.229	1.281	1.60	3.78
15	0.90	1.025	1.065	1.118	1.175	1.236	1.295	1.64	11.03
16	1.00	1.025	1.071	1.118	1.175	1.239	1.307	1.66	(a)

(a) The relative viscosities of these could not be determined as the slips were too viscous to flow from the viscosimeter.

RESULTS OF WORK

Sodium Hydroxide and Georgia Kaolin. Table I and Figure 1 show the results on Georgia kaolin with sodium hydroxide. In Figure 1 the iso-viscosity lines show that the decrease in viscosity is retarded up to a certain point when suddenly there is a drop to minimum viscosity, and then with larger additions of alkalies there is a gradual increase in viscosity. The point of minimum viscosity is much better defined in the high clay slips than in the low clay slips because the change in viscosity in the low clay slips is very low. It is interesting to note that when sodium silicate or sodium carbonate is used in the place of sodium hydroxide (see Figures 2 and 3), the decrease in viscosity is not retarded as is the case when sodium hydroxide is used. This is probably due to the presence of flocculating impurities[14] such as calcium hydroxide which are precipitated

[14] Förster, F., Ueber das Gieszen des Tones: *Chem. Industrie*, 28, 1905, pp. 733-740.


TRANS. AM. CER. SOC. VOL. XIX
FIG. 1
SCHURECHT
100 Water
Equal NaOH to clay ratios
Equal NaOH to water ratios
VISCOSITY DIAGRAM OF GEORGIA KAOLIN WITH SODIUM HYDROXIDE
1.05
1.12
1.22
1.40
1.72
50 Water 50 Clay
50 Water 50 Clay 0.5 NaOH

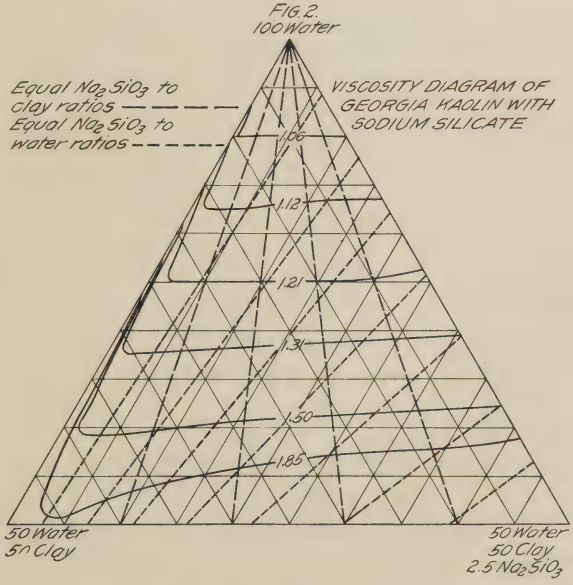


FIG. 2.
100 Water
Equal Na_2SiO_3 to clay ratios
Equal Na_2SiO_3 to water ratios
VISCOSITY DIAGRAM OF GEORGIA KAOLIN WITH SODIUM SILICATE
1.06
1.12
1.21
1.31
1.50
1.85
50 Water 50 Clay
50 Water 50 Clay 2.5 Na_2SiO_3

when reagents like sodium carbonate are added thus rendering them harmless.

The dash lines have been drawn through points having equal alkali to clay ratios, while the dotted lines have been drawn through points having equal alkali to water ratios. The points showing a sudden drop in viscosity follow a line having almost the same alkali to clay ratio which is about 0.07 percent. in terms of clay. With the high clay slips more than 0.08 percent. is necessary to produce this drop which may be due to the fact that the electrolyte is not quite as highly ionized in this case as it is in the more dilute solutions. In following the dotted lines from the high clay slips to the low clay slips, it is found that points which show minimum viscosity in the high clay slips pass to points showing a re-thickening in the high water slips. This shows that the practice of calculating the alkalies necessary to produce a certain degree of dispersion in terms of water, regardless of how much clay is present is wrong where the clay and water contents vary. For instance in the slips containing 50 percent clay and 50 percent water, minimum viscosity is reached when the alkali is 0.18 percent in terms of water. When this concentration of electrolyte in water is reached in the case of slips containing 15 percent clay, a decided increase of viscosity over the minimum occurs. This shows that the state of dispersion is dependent to a large extent upon the clay in the slip.

A viscosity of 1.16 is maintained in some cases in the washing of clays.[15] If no alkalies are used this viscosity is reached when the slip contains about 13 percent. clay. When sodium hydroxide sufficient to produce minimum viscosity is added, this viscosity is not reached until the slip contains about 20 percent. clay. At the given viscosity it is possible to treat about 54 percent. more clay by using sodium hydroxide than without any alkalies. Other factors such as weather conditions would vary these figures somewhat.

Sodium Silicate and Georgia Kaolin. The results with sodium silicate on Georgia kaolin are shown in Table II and Figure 2. Here a decrease to minimum viscosity is seen when

[15] A viscosity of 1.068 is recommended by Sproat, I. E., Kaolin Refining: *Trans. Amer. Cer. Soc., Vol. XVIII*, 1916, p. 778. After making density corrections this was found to be about 1.16.

about 0.25 percent. of sodium silicate is added in terms of clay. This electrolyte does not thicken the slip as readily as sodium hydroxide when additions of electrolyte larger than that required to produce minimum viscosity are added. Sodium silicate produces a slightly greater drop in viscosity than sodium hydroxide.

Here again the point of minimum viscosity is less defined in the low clay slips than in the high clay slips. In the following the dotted lines (Fig. 2) representing equal salt to water ratios from the high clay slips to the low clay slips, it is seen that points which show minimum viscosity in the high clay slips pass through points showing slight signs of re-thickening in the low clay slips. In following the dash lines representing equal salt to clay ratios from the high clay slips to the low clay slips, no change from minimum viscosity to a re-thickening of slip can be found. The sharp drop to minimum viscosity follows quite closely a line representing equal salt to clay ratios.

TABLE II — VISCOSITY OF GEORGIA KAOLIN WITH SODIUM SILICATE.

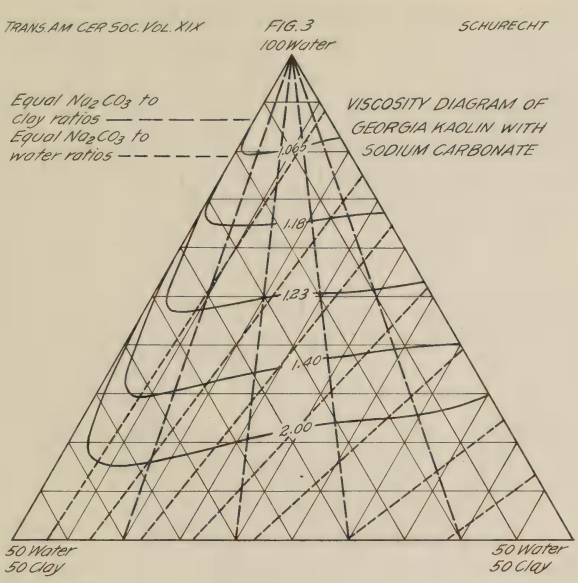
NO.	PERCENTAGE Na_2SiO_3 IN TERMS OF DRY CLAY	5% CLAY 95% WATER	10% CLAY 90% WATER	15% CLAY 85% WATER	20% CLAY 80% WATER	25% CLAY 75% WATER	30% CLAY 70% WATER	40% CLAY 60% WATER	50% CLAY 50% WATER
1	0.00	1.032	1.098	1.199	1.391	1.722	2.587	(a)	(a)
2	0.08	1.028	1.081	1.150	1.231	1.386	1.708	1.91	(a)
3	0.12	1.025	1.060	1.123	1.210	1.345	1.478	1.53	(a)
4	0.14	1.025	1.061	1.118	1.180	1.310	1.392	1.49	(a)
5	0.16	1.025	1.061	1.112	1.163	1.261	1.306	1.48	3.02
6	0.18	1.025	1.061	1.108	1.158	1.231	1.270	1.46	2.13
7	0.20	1.025	1.061	1.108	1.151	1.220	1.270	1.46	....
8	0.22	1.025	1.061	1.106	1.149	1.220	1.270	1.46	1.88
9	0.26	1.025	1.061	1.103	1.149	1.214	1.270	1.46	....
10	0.30	1.025	1.061	1.103	1.149	1.214	1.270	1.46	1.88
11	1.00	1.025	1.061	1.103	1.153	1.220	1.270	1.48	2.16
12	3.00	1.025	1.061	1.103	1.154	1.220	1.281	1.53	2.68
13	5.00	1.025	1.061	1.103	1.156	1.227	1.295	1.58	3.55
14	7.00	1.025	1.061	1.103	1.156	1.227	1.302	(a)	(a)
15	10.00	1.025	1.061	1.103	1.157	1.227	1.308	(a)	(a)

(a) The relative viscosities of these could not be determined as the slips were too viscous to flow from the viscosimeter.

In slips containing no alkalies, a viscosity of 1.16 is reached when the slip contains about 13 percent clay. When sufficient sodium silicate to produce minimum viscosity is used, the slip does not reach a viscosity of 1.16 until it contains about 20.5 percent clay. At the viscosity 1.16, it is possible to treat about 58 percent more clay by using sodium silicate than without using any alkalies.

Sodium Carbonate and Georgia Kaolin. The effect of sodium carbonate on Georgia kaolin is shown in Table III and Figure 3. This slip reaches minimum viscosity when about 0.60 percent alkali in terms of clay is added. Slightly more than this is necessary in the high clay slips which is probably due to the fact that the electrolyte is more concentrated in this case than in the high water slips, and hence is not as highly ionized as it is in the high water slips. It is obvious that sodium carbonate is much "weaker" chemically than sodium hydroxide or sodium silicate because the drop in viscosity is much less, and the amount necessary to produce minimum viscosity is much greater than was necessary in the case of the other electrolytes.

In following the dotted lines representing equal salt to water ratios, from the high clay slips to the low clay slips we again pass from points of minimum viscosity in the high clay slips through points showing re-thickening in the high water slips. In following the dash lines representing equal salt to clay ratios, in a similar way no change from minimum viscosity to re-thickening can be detected.


TRANS. AM CER SOC. VOL. XIX
FIG. 3
SCHURECHT
100 Water
Equal Na_2CO_3 to clay ratios
Equal Na_2CO_3 to water ratios
VISCOSITY DIAGRAM OF GEORGIA KAOLIN WITH SODIUM CARBONATE
1.063
1.18
1.23
1.40
2.00
50 Water 50 Clay
50 Water 50 Clay

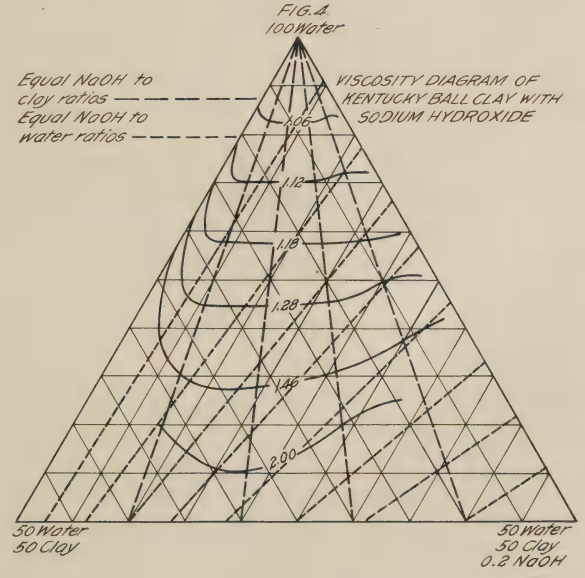


FIG. 4.
100 Water
Equal NaOH to clay ratios
Equal NaOH to water ratios
VISCOSITY DIAGRAM OF KENTUCKY BALL CLAY WITH SODIUM HYDROXIDE
1.06
1.12
1.18
1.28
1.46
2.00
50 Water 50 Clay
50 Water 50 Clay 0.2 NaOH

TABLE III — VISCOSITY OF GEORGIA KOALIN WITH SODIUM CARBONATE.

NO.	PERCENTAGE Na_2CO_3 IN TERMS OF DRY CLAY	5% CLAY 95% WATER	10% CLAY 90% WATER	15% CLAY 85% WATER	20% CLAY 80% WATER	25% CLAY 75% WATER	30% CLAY 70% WATER	35% CLAY 65% WATER	40% CLAY 60% WATER	50% CLAY 50% WATER
1	0.00	1.032	1.098	1.199	1.391	1.722	2.587	(a)	(a)	(a)
2	0.04	1.031	1.083	1.177	1.219	1.386	2.070	(a)	(a)	(a)
3	0.08	1.031	1.079	1.160	1.208	1.333	1.537	(a)	(a)	(a)
4	0.12	1.030	1.073	1.144	1.202	1.280	1.428	1.92	3.17	(a)
5	0.16	1.030	1.067	1.133	1.190	1.264	1.387	1.83	2.45	(a)
6	0.20	1.029	1.067	1.115	1.176	1.251	1.355	1.78	2.10	(a)
7	0.22	1.029	1.067	1.111	1.176	1.243	1.353	1.73	1.91	(a)
8	0.24	1.031	1.067	1.107	1.170	1.238	1.337	1.62	1.91	(a)
9	0.26	1.030	1.066	1.108	1.170	1.231	1.320	1.54	1.83	(a)
10	0.30	1.029	1.066	1.108	1.168	1.231	1.300	1.51	....	4.56
11	0.34	1.029	1.065	1.108	1.165	1.220	1.289	1.43	1.65	3.92
12	0.40	1.028	1.064	1.108	1.163	1.215	1.283	1.40	1.61	3.65
13	0.70	1.028	1.065	1.108	1.164	1.215	1.283	1.40	1.55	3.48
14	1.00	1.028	1.066	1.108	1.167	1.220	1.289	1.42	1.58	5.66
15	2.00	1.028	1.066	1.109	1.171	1.231	1.307	1.46	1.70	(a)
16	3.00	1.029	1.071	1.112	1.174	1.238	1.337	1.51	1.85	(a)
17	4.00	1.029	1.072	1.114	1.179	1.243	1.368	1.62	2.90	(a)
18	5.00	1.029	1.074	1.118	1.182	1.250	1.415	1.84	4.02	(a)

(a) The relative viscosities of these could not be determined as the slips were too viscous to flow from the viscosimeter.

In slips containing no alkalies, a viscosity of 1.16 is reached when the slip contains about 13 percent. clay. When the amount of sodium carbonate necessary to produce minimum viscosity is added, the slip does not reach this viscosity until it contains about 20 percent. clay. At the above viscosity, it is therefore possible to treat about 50 percent. more clay by using sodium carbonate than when no alkalies were used.

Sodium Hydroxide and Kentucky Ball Clay. Table IV and Figure 4 show the effect of sodium hydroxide on Kentucky ball clay. The point of minimum viscosity is reached when about 0.14 percent sodium hydroxide in terms of clay is added. The thickening of the slip upon adding more electrolyte than the amount necessary to produce minimum viscosity is more marked in this case than in the others.

Here again we find, in the following the dotted lines from high clay slips to low clay slips, we pass from points showing minimum viscosity to points showing a re-thickening of the slip.

The viscosity 1.16 is reached in slips containing no alkalies when it contains about 13 percent. clay. When sodium hydroxide is used, this viscosity is not reached until the slip contains about 20 percent clay. By using sodium hydroxide about 54 percent more clay can be treated before the viscosity 1.16 is reached than when on alkalies are used.

TABLE IV — VISCOSITY OF KENTUCKY BALL CLAY WITH SODIUM HYDROXIDE.

NO.	PERCENTAGE NaOH IN TERMS OF DRY CLAY	5% CLAY 95% WATER	10% CLAY 90% WATER	15% CLAY 85% WATER	20% CLAY 80% WATER	25% CLAY 75% WATER	30% CLAY 70% WATER	35% CLAY 65% WATER	40% CLAY 60% WATER	50% CLAY 50% WATER
1	0.00	1.036	1.090	1.201	1.333	1.700	(a)	(a)	(a)	(a)
2	0.04	1.031	1.080	1.123	1.168	1.260	1.391	1.88	(a)	(a)
3	0.08	1.030	1.072	1.122	1.165	1.240	1.320	1.45	1.73	7.81
4	0.10	1.030	1.072	1.123	1.163	1.242	1.320	....	....	....
5	0.12	1.030	1.072	1.122	1.160	1.242	1.320	1.44	1.53	2.25
6	0.14	1.029	1.073	1.123	1.160	1.242	1.320	....	....	....
7	0.16	1.029	1.073	1.122	1.161	1.242	1.319	1.43	1.56	....
8	0.18	1.029	1.075	1.122	1.161	1.242	1.321	1.45	1.60	2.23
9	0.20	1.029	1.075	1.122	1.162	1.244	1.321	....	....	....
10	0.22	1.029	1.075	1.122	1.162	1.245	1.322	1.47	1.68	3.31
11	0.26	1.029	1.075	1.122	1.162	1.247	1.344	1.49	1.74	(a)
12	0.30	1.029	1.077	1.130	1.166	1.259	1.368	1.56	2.44	(a)
13	0.34	1.031	1.077	1.133	1.168	1.276	1.451	2.29	(a)	(a)
14	0.38	1.031	1.075	1.132	1.185	1.290	1.501	(a)	(a)	(a)

(a) The relative viscosities of these could not be determined as the slips were too viscous to flow from the viscosimeter.

SUMMARY

Based upon the results of this investigation the author has drawn the following conclusions in such cases where the water is relatively pure:

While the chemical activity of the electrolyte on clay may be slightly less in the more concentrated solutions than in the dilute solutions, the keeping of the ratio of electrolyte to clay

constant is much more important in maintaining minimum viscosity in clay slips in which the clay and water contents vary, than keeping the ratio of electrolyte to water constant.

In the case of sodium hydroxide and Georgia kaolin, the decrease in viscosity is retarded up to a certain point when small quantities of alkali are added, and then when more is added there is a sudden drop to minimum viscosity. When sodium carbonate or sodium silicate are used in the place of sodium hydroxide the decrease in viscosity is not retarded as is the case when sodium hydroxide is used.

In agreement with Bleininger's work,[16] sodium silicate and sodium hydroxide are found to be much more effective reagents to produce a decrease in viscosity than sodium carbonate.

The limits in which sodium hydroxide produces minimum viscosity are small while the limits within which sodium silicate and sodium carbonate produce minimum viscosity are relatively large.

The viscosity data would indicate that 50-58 percent more clay could be treated when alkali sufficient to produce minimum viscosity is added than when no alkalies are added. Before anything definite can be said about this, however, it will be necessary to try this on a commercial scale.

In conclusion the writer wishes to acknowledge his indebtedness to Prof. A. S. Watts for suggesting this work and for many helpful suggestions during the work.

[16] Bleininger, A. V., Use of Sodium Salts in the Purification of Clays and in the Casting Process: *Bureau of Standards Tech. Paper 51*, 1915, p. 39.

NOTES ON FLOW OF CLAY THROUGH HOLLOW WARE DIES

BY GEORGE D. MORRIS.

The notes, upon which this paper is based, have been collected in the practical handling of five distinct clays. They cover three grades of shale and two grades of fire clay. The extremes were not reached either in the shales or the fireclays, but taking the clays as a whole, the extreme limit of plastic and non-plastic clays were handled. In the manufacturing and forming of the ware the degree of plasticity is very important. A very plastic clay may form all right, but not stand the drying process, and the same may be true with an extremely non-plastic clay. The satisfactory flow of clay through hollow-ware dies is a complicated problem. We have found from study of different clays, that each clay may be classified by just the way it flows through the dies.

Visit as many plants as you wish and inquire concerning the pressure it requires to press the clay into the various sizes, and they will invariably give you the number of pounds pressure on the boilers. Referring to the press it would be the pressure on the steam cylinder C, on top of piston head P, Fig. 1. In most cases this would be about 125 pounds per square inch. That is as far as the question of pressure is generally studied. By examining different presses, it will be found that with the same size steam cylinder, there will be a different sized clay cylinder, according to the size of pipe made on that particular press, and this would give different pressure per square inch in the clay cylinder. The clay cylinders will be found to vary in size, but are readily increased or decreased by putting in a bushing when so desired. The relative pressure of the two heads on the piston varies inversely to the area of the heads. Boiler pressure times area of piston head *P*, divided by the area of the piston head *M*, will give the mean effective pressure on clay cylinder head. The area of the 44 in. piston head times 125

pounds, equals 189,250 pounds pressure. This pressure transmitted to an 18 in. clay cylinder will give a pressure of 750 pounds per square inch. The pressure of 750 pounds is six times the original boiler pressure. This enormous pressure has a very decided effect on the flow of clay through the hollow-ware dies.

The explanation will be more easily understood in the following practical illustration. Take a six-inch sewer pipe. We desire a pipe of about ¾ inch shell thickness, that will run out straight and be sufficiently stiff to hold to shape while being handled from the press to the drying floors. It has been noted that the plasticity governs the stiffness and consistency of the clay running through the die. A plastic clay will hold its shape in a softer state than a non-plastic clay, and does not require to be pressed as close together as a non-plastic clay.

To make a six-inch pipe run from the die straight, the finish on the die and bell must be of sufficient length to compress the clay into a sufficiently solid body, so that the clay will hold its shape, (the finish of dies is shown by *G* and *H* in Figs. 1, 2 and 3). Second—The pipe must be so well pressed and knit together that it will pull loose from the socket former and hold its own weight, remaining suspended long enough to permit it to be broken off after the socket former is freed from the pipe.

With a clay having sufficient plasticity and stiffness at a certain pressure to stand the required handling, a certain rule has been found which has worked out in a majority of cases. The length of finish and pounds pressure vary inversely to the plasticity of the clay.

The less plastic a clay is, the more pressure required to press the clay to stand handling. The pressure needed varies inversely as the plasticity. To obtain more resistance in the die, the finish on die and bell must be lengthened. Whenever the finish is lengthened, the pressure must be increased if the clay is going to be stiff enough to stand handling — because when the finish is longer the resistance is greater, and with no increase in pressure the press would not press out the clay.

The relative increase of each cannot be given, but a few illustrations will be cited. A non-plastic, very gritty fire clay

failed to give satisfaction with a finish of 4 in. and pressure of 550 pounds. Raising the pressure to 750 pounds per square inch a very good pipe was made. A very plastic clay used on a die with a ¼ in. finish at 450 pounds pressure proved unsatis-

TRANS. AM. CER. SOC. VOL. XIX MORRIS

CROSS SECTIONAL VIEWS OF SEWER PIPE PRESS

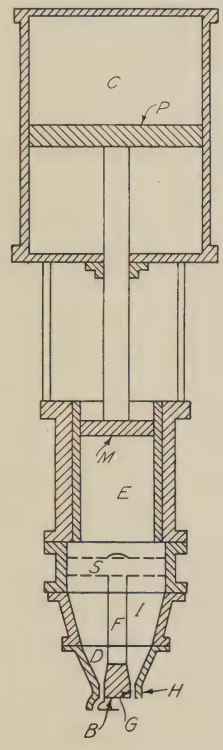


FIG. 1

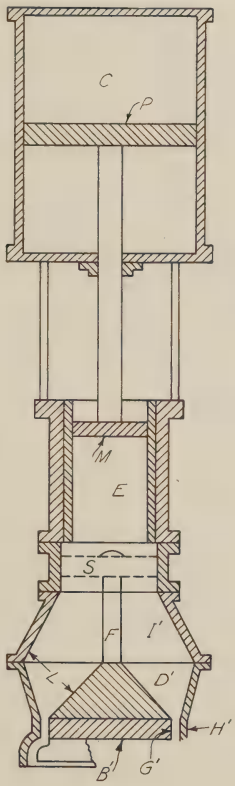


FIG. 2

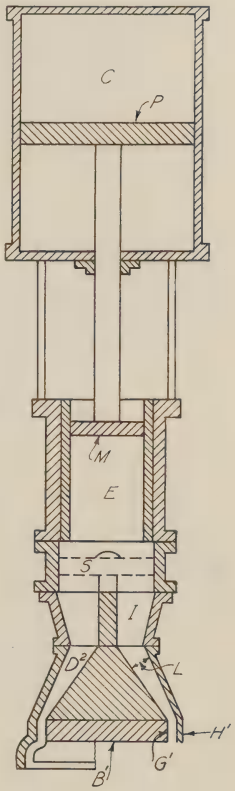


FIG. 3

factory. By increasing the finish to 2 inches and with the same 450 pounds pressure the result was not improved, as the clay had to be soft at this pressure to stand handling. When the pressure was increased to 650 pounds, good pipe were made,

and there was practically no loss from dropping off of crooked pipe.

The larger sizes will vary under the same ratio of plasticity to pressure and finish of dies and bells. The thickness of the shell has a very marked effect on the length of finish. The required increase of finish is hard to determine, but varies directly as the shell thickness. The exact proportion would form a very interesting research problem.

The statements in this paper have been gathered from practical data; some overlap, and to the critical mind may be found to conflict, but nevertheless they would be proven by a more accurate method of determining the exact degree of plasticity, stiffness, etc.

The exact amount of pressure and length of finish required to make a column of clay run out straight from a six-inch sewer pipe die has been discovered by the cut-and-try method. The essential requirement of a die is to make a column of clay run straight and smooth. It must press the clay together so that there will be no unequal strains. In the flow of the clay through a long finish die, the column is formed and compressed sufficiently, so that when the column leaves the die the clay will hold together rather than fall apart. If there is an unequal pressure on the column of clay, a strain is set up, and if the column does not break apart upon leaving the die, it will do so in drying. These unequal strains are often caused by different length of finish of die and bell or an obstruction somewhere. In Figure 3, the clay has to flow so far through so small a space that the clay will not run unless just right all of the time.

A short finish of ¼ inch may be sufficient in a very plastic clay, if the column of clay is run very slowly through the die. Increase the speed and the clay will not form a compact column. Increasing the length of finish to 2 in. or 4 in. will compact the clay solid enough so that a straight column will run out. A good illustration of the effect of short and long finish is that of nozzle used on water hose. A short nozzle will spray the water and a long nozzle with just a slight taper will shoot the water out in one straight solid column. The same holds true

with a sewer-pipe die. The column of clay must not spray, but must run in a straight line.

From the above statements it would appear desirable to make all long-finish dies; but as again with the water nozzle, too much nozzle or friction causes unequal flow of water. Too much finish retards the clay, causing unequal flow.

The construction of dies is very interesting, and many times it is a very troublesome problem to overcome some of the difficulties. A press having a clay cylinder of 18 inches has been cited in the above paragraph, and invariably the "old timer" will say a press of that size cylinder will not make larger pipe than an eighteen-inch successfully. Understand right here it is not the clay cylinder that forms the pipe, it is the extension connecting the die to the clay cylinder. Figure 2 shows a cross section of a large size die, and if plenty of room is given at L, no trouble will be experienced. If the die is constructed as in Figure 3, there will be no end of trouble with the die due to the uneven running of clay through such a narrow space. Laminations and blisters are augmented by the narrow approaches to the finish of the die.

WET CLAY ELEVATOR

BY GEO. D. MORRIS.

In the clay industry, as in every other industry, we are constantly seeking improvements and new and better methods in order to increase and improve results with the same or less expense. For instance we have adopted the electric elevator for our freight elevator, and have adopted many other improvements over the old time methods of handling clay.

The elevating of clay by bucket elevators is not a new means of raising the clay to the top story from the basement, where the clay usually finds its first resting place. Neither the height nor the style of clay elevator will be discussed in this paper; only the bottom part or boot as it is commonly known.

The boot of all clay elevators is the source of 99 percent of the clay man's troubles in operating a bucket elevator. First and almost always last the old saying comes that the clay elevator is "plugged up." "Plugged up," means that the boot is full of clay, the elevator has stopped, and maybe a dozen or more buckets have been torn off, and that part of plant supplied by the elevator is shut down waiting on clay.

First we will present a sketch of the type of clay elevator with which most clay men are familiar. Figure 1 is a cross-section of a bucket elevator showing the pullet, belt, shelf, buckets, chute and bottom or pit. Chute *H*, feeds the clay into the buckets of elevator or into space *J*, whenever there are no buckets at the points *AA*. In cases where the buckets are 12 to 24 inches apart there is a large space for the clay to pass down into the pit *G*. The falling of the clay into the pit *G*, is just the opposite way from which it is supposed to travel. Whenever the clay is permitted to fall into pit *G*, we have the work of emptying the pit quickly or the filling up of the pit, stopping the elevator. After the clay has passed below the line *D D*, the center of the boot pulley, the elevating of the clay from the pit turns the elevator into a steam shovel by making

the buckets dig the clay out of the pit. Illustrating the digging of the elevator bucket, we take bucket *B-6*, as it passes around the lower part of pulley *E* and the pit *G*, filled with clay up to point *A A*. The bucket is drawn through by the belt forcing the clay in directions of lines of force *N* and *N'* If the pit is so full that the clay will not permit the bucket to pass through, the bucket will be torn off or the belt stopped.

No time need be spent telling how to clean out the pit nor in describing patent boots which are claimed by machinery salesmen to be easily cleaned, but will pass on and endeavor to tell you how to prevent the clogging up or tearing off of buckets.

Figure 2 shows nothing more than just a little change in the chute *H*, from the type of elevator shown in Figure 1. In Figure 1, you note that *A* is on the line with the center of pulley *E'* when pulley is at its highest position. The bottom of chute *H*, is shown to be just a few inches above the line *D D'*. In Fig. 2 *A* is on the same line *D D'*, but *A'* is considerably farther away from *D D'* in Fig. 1 than in Fig 2. This distance *AA'* in the figure is governed by the distance represented by *C C'*. The distance *C C* equals the distance between the centers of the buckets fastened to the belt. For example if buckets are placed 24 inches apart, the distance *A A'* would be 24 inches. With the chute *H*, emptying the clay into elevator boot at a point *A'*, a distance *C C'* or 24 inches above the center line of pulley *E'*, ninety-nine percent plus of all clay goes up and what goes down into pit *G*, can be easily taken care of by the buckets at their leisure. With the chute *H*, Fig. 2, placed at *C C'* distance above the center line of pulley *E'*, there always is a bucket in space *J*. With a bucket in space *J* all of the time, and the side of boot at *A A'* with only a half inch clearance between boot and bucket, very little clay can slip by into the pit *G*.

When the bucket *B-1* is at point *A'* it is full, and *B-2* bucket is empty at point *A*. After the bucket *B-2* passes the point *A'* and reaches *B-4*, the clay in chute *H*, slides down and fills bucket *B-2* which has reached the point of *B-5*. If there is more clay than can be taken care of on bucket *B-2*, it is forced upwards in direction of *N*. When the bucket passes the

WET CLAY ELEVATOR

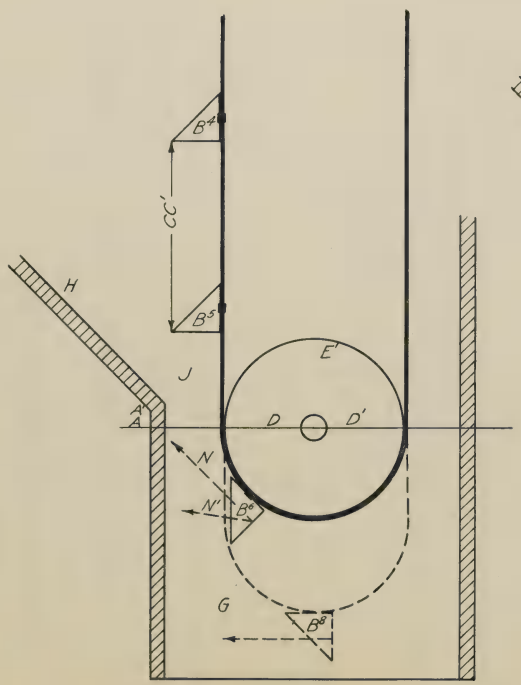


FIG. 1

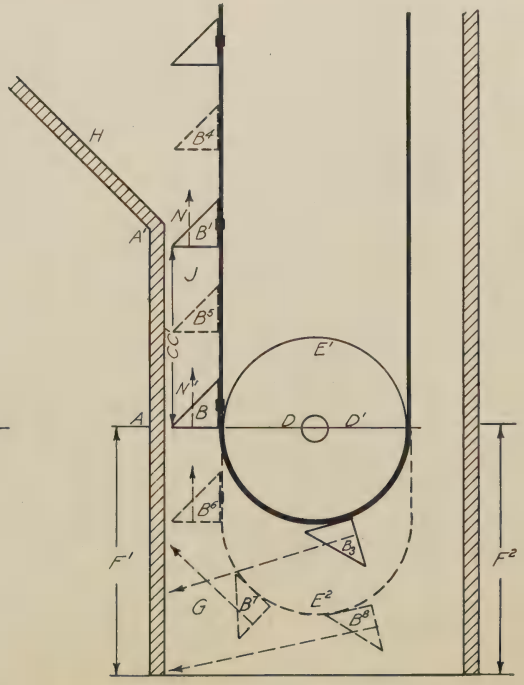


FIG. 2

chute H at A' and has more clay than it can carry, the surplus clay will fall off into chute H and slide into the next empty bucket.

An example of the two types of elevators handling stiff-mud clay may be cited. First, an elevator of 12 in. by 6 in. by 6 in. shelf buckets running at a speed of 500 feet per minute was elevating about 10 tons of clay per hour under favorable conditions and would clog upon an average of about 3 times daily if not crowded, and if crowded would clog up in 15 minutes after being cleaned. Most likely some will say that elevator was running too fast. Slower speeds were tried with most discouraging results. After consulting some engineers in and around St. Louis, a combination of slower speed and larger elevator was adopted. What to do with the boot remained a vital question. After searching many catalogues, an elevator for elevating stone was shown using this higher chute. An elevator was constructed about 18 months ago under these principles, and has established since a record of never being clogged up and not one bucket torn off nor replaced. A remarkable record when compared with the old elevator which stopped more times in one hour than the new type has in over a year's time.

The old type of elevator with a 12 in. by 6 in. by 6 in. shelf bucket at a speed of 500 feet per minute has a theoretical capacity of about the same as the new type elevator with 20 in. by 8 in. by 8 in. shelf buckets at a speed of 220 feet per minute. Under actual working conditions 10 tons per hour was the limit for the old type, and during winter months it was necessary to keep one man knocking clay out of the returning buckets. The new type takes care of 1400 pounds of clay in 20 seconds, or a total of 120 tons per hour if given the clay. Not once was it necessary to have any buckets cleaned during the worst winter months.

Installing of the new type of elevator doubled the capacity of the wet pans. The wet pan required one minute for mixing and with the old elevator 2 minutes for emptying. With the new type of elevator, the wet pans are emptied in 10 seconds.

RELATION OF FUSING POINT OF ASH TO AVAILABILITY OF COAL FOR BURNING CERAMIC WARES

BY RICHARD R. HICE

The importance of this fuel supply is not fully appreciated by the manufacturer of clay goods. One may be careful to secure the very highest grades of clays and other materials going into his products — materials which tests show are the best suited for his needs — his methods of working may be the best possible, and his goods when ready for the kiln may be perfect in every way, but he may fall down in the burning of his wares. When we really consider all the facts, we must conclude that fuel is, perhaps, the most important raw material with which the manufacturer of clay goods has to deal.

The general requirements of fuel for ceramic work are essentially the same as for other uses, but with special emphasis laid upon some factors which must, or must not, be present in a clay-burning fuel. We are accustomed to the ordinary proximate analysis of coal, volatile matter, fixed carbon and ash, with a special determination of the sulphur present, and occasionally of the phosphorus. Occasionally we have an ultimate analysis, but usually give it the little attention it deserves.

We generally regard sulphur as the most important impurity present. The bad effects of sulphur cannot be denied, nor the fact that sulphur in many classes of clay goods is especially harmful, yet if the drafts are properly handled quite a high sulphur coal may often be used without any bad effects. Another quality of fuel necessary for good results in a kiln is "reach". It is not only necessary that there be the right quantity of heat generated in a kiln, but it must be so distributed that it reaches all portions of the kiln and the ware in it, and in some classes of ware a uniform character of the kiln gases is essential. If the fuel does not have this "reach", we can still have all the required quantity of heat generated, but the fire

boxes will be overheated, a portion of the ware overburned, and some of it underburned. The blame is often charged to the construction of the kiln, and changes are made which have no bearing on the real matter at fault.

The heating value of the fuel is important. If this is too low it is impossible to burn the ware, while a high heating value coal, other factors being the same, means less quantity of fuel and less labor in burning.

For the present purposes we may consider coal as a complex substance, composed of various hydrocarbon compounds, some fixed carbon, earthy materials of various kinds, with other dilutents in the way of hydrogen, oxygen and nitrogen. The earthy materials compose the ash, which may also be considered as a dilutent, but it is much more than this in practice.

The principal constituents of ash are silicon, calcium, magnesium, iron, aluminium, sulphur, oxygen, with varying quantities of the alkalies, and other ingredients to a greater or less degree.

In a study of coal we find that, as we receive it, the ash content consists of three portions. First, there is that portion of the ash which is inherent in the coal substance itself. The plants which formed the coal beds secreted some silica, and small quantities of other earthy materials, and in the passing of the plants into coal this earthy content was necessarily retained. This portion of the ash is, therefore, diffused, more or less regularly, through the coal bed. Secondly, a portion of the ash is found in certain parts of the bed which we cannot call coal proper. This is in the form of mud cracks of various sorts which have become filled with earthy materials. Slate veins, which mark times during the deposition of the coal when the waters were muddy and earthy matter was deposited along with the plant remains. What we designate as bony coal, where there is a large percentage of ash present, often in thin laminæ between laminæ of high grade coal. Third, we have that portion of the ash which results from mining operations. Some of this comes from portions of the roof dropping and becoming mingled with the coal. This is especially the case where the coal is shot from the solid, and the roof shattered so that it

flakes off, and these flakes are loaded with the coal. Another portion of the ash due to mining comes from the floor of the mine, especially where the underclay may be soft. This portion may be quite a factor, and is irregular in amount and composition.

It is evident some of these sources of ash may be reduced. The bone coal may not be mined if at the bottom of the bed, or if mined may be thrown out and not loaded. If the slate is of any considerable thickness, it may be thrown aside. Part of the sulphur may be discarded in loading — in some mines where it is in the form of pyrites it is sorted out and sold for making acid. The portion from the roof may be kept down by proper mining methods, and at times this is an important factor. The portion from the floor can only be reduced by proper mining methods. This portion will vary with the character of the floor, its hardness, composition, smoothness, etc.

The part of the ash due to mining cannot well be reduced except by washing. Where run-of-mine coal is used all of this material is embraced in the coal as shipped, and where the slack is removed very often the ash content of the coal is so reduced as to make quite an appreciate reduction from the total average, as well as to make a great change in the relative proportion of the ingredients of the total ash, and of its fusing point.

The ash from these three sources will differ greatly, both chemically and mineralogically, and hence each portion of the total ash will act differently in the process of burning the coal, regardless of the character of the furnace used, the temperature of the furnace, or any other factor in the firing.

If we consider the process of burning coal, not technically, but as we all see it in practice, we learn wherein the ash content of the fuel may be the ruling factor in the selection of any particular coal, or of its rejection. The fuel bed in a furnace consists of several portions or layers. First, immediately over the grate bars there is more or less of a perfect layer of ashes and clinker. The fuel part of this portion of the bed has been exhausted, or it is so covered up by the ashes and clinker that it is not longer available. Over this lies a bed of more or less incandescent carbon — that portion of the coal which remains

after the lighter hydrocarbons have been driven off. In this layer of the fuel bed all the ash of the coal which the layer represents is present, except such portion as may have melted and passed down to the underlying ash bed. Overlying this incandescent bed is a layer which varies from raw coal on the top to the character of the incandescent carbon layer.

When fresh coal is placed on the fire bed the first action is the heating up of the cold fuel by the heat of the lower incandescent carbon zone, or of the overlying, fresher fuel. This action of course tends to lower the temperature of the fire box. When the fresh coal is sufficiently heated up, the lightest hydrocarbons present are dissociated and driven off. If there should be no free oxygen present the fire box will practically be a retort, and this portion of the fuel would be called gas and under ordinary conditions would pass up the chimney and be lost. As the temperature of the fresh coal increases, heavier and heavier hydrocarbons are driven off, until only the ash and the fixed carbon remain. In a fire box the gases thus driven off come into contact with air which has found its way upward through the lower portions of the fuel bed. In passing through the bed, the air is heated, and coming into intimate contact with the fresh gases unites with them, burning wherever the proper admixture of gas and air may take place. Under ideal conditions, with the proper draft, the last of the gases would be consumed just as the products of combustion leave the kiln.

The inflow of air through the fuel bed is most important. If there is just sufficient air passing through the grate bars and the overlying ash and clinker to supply the wants of the fixed carbon portion of the fuel bed, there will not be any oxygen in the kiln to combine with the gases set free from the fresher coal. In practice this is never the case at least not completely so.

The ash is left in the fire box, on the grate bars or on the top of the ashes forming the support of the fuel bed. The upper portion of the ash from the burning coal is at the temperature of the lower portion of the fuel bed. Here the fixed carbon is being consumed, and with its disappearance the particles of

ash come into closer and ever closer contact. Now if the ash, which is of such varying composition both chemically and mineralogically, is of such character that its fusing point is higher than the temperature of the fire box, the ash remains an unaltered, "dry", and loose mass of earthy matter. In such condition there is free passage for air through it with but little friction or obstruction, and in such case there is ample air passing through the fuel bed, in excess of that needed in the fire box itself, to burn the free hydrocarbons within the kiln, and the coal has "reach".

If, however, the character of the ash is such that it fuses at or below the temperature of the incandescent portion of the fuel bed, an impure glass is formed, more or less viscous at that temperature, and this glass surrounds portions of the coal and prevents its combustion. This partly fused mass forms a more or less continuous body over the bottom of the fire box and prevents free access of air to the fuel which not only cuts off thereby air needed to consume the free hydrocarbons in the kiln, but may prevent good combustion in the fire box itself. This action of the ash is very often the most important factor in a coal, and one that is really neglected in most cases.

The subject of coal supply is at all times important, for when using coal we are always subject to a change in the source of supply, if for no other reason than the working out of old mines. With the passing of natural gas it is especially important. Of late years it has been drilled into us that we should buy our coal on the basis of its thermal value. This may be all right for some uses. I know of coals which were most efficient when burned in the locomotive, but which fell down utterly in the brick kiln. There was no difference in the heating value of the coal, but the difference was in the temperature of the fire box. We can get no information from a chemical analysis of the coal, unless in abnormal cases, for the relation of a chemical analysis of the ash of a coal has the same relation to the fusing point that an analysis of a clay has to its point of failure, and that is usually none. The fusing point of the ash must be directly determined in each case; and as yet there has not been developed any standard method of so doing. What the relation of the

fusing point of the ash as found in the laboratory may be to that found in practice has not been determined.

It is possible to use a part of a coal deposit which will give a high temperature fusing ash, while the remaining portion of the bed, perhaps not a foot in thickness, will so alter the average ash content, both in quantity and quality, as to render the use of the entire coal impossible. Similar conditions exist as to the sulphur content. It has long been known that often the lower foot or eighteen inches of portions of the Pittsburgh coal carries so much sulphur as to render the use of the whole bed impossible for metallurgical coke.

To return to the fire box. It is true the rate of combustion depends upon the air supply to the fuel in the furnace. We generally measure this by the difference in draft pressure across the fuel bed. This measure may be correct, if all other conditions are the same, but if the rate of flow of the air through the grate and fuel bed varies by reasons of obstructions, the draft readings do not give comparative results. Such obstructions may vary with the thickness of the fuel bed itself, with the character of the coal as regards its size, and more especially as regards the amount of ash on the grate bars, the portion of the ash which is fused, and the proportion of the grate bars covered or obstructed by this fused clinker.

Ash may fuse at as low a temperature as 2000° F., while with other coals the fusing point may be over 3000° F. It needs no argument to show that a smaller quantity of total ash may give a much greater amount of fused material in fire boxes of equal temperatures, than a coal with a higher percentage of ash. It is equally obvious that a small quantity of low fusing ash, which has a correspondingly high degree of fluidity, will run over and obstruct a greater percentage of grate surface, or of the surface of the accumulated ash on the grate bars, than a much larger quantity of a higher fusing ash.

Bailey[1] has pointed out that "the real measure of clinker formation is the difference between the fusing temperature of the ash and the temperature to which the ash is subjected. Thus

[1] Paper read before the Ohio Society of Mechanical, Electrical and Steam Engineers. Nov. 18, 1911.

if an ash with a fusing point of 2000° F. was in a fire box heated to 2100° F. the amount of clinker would be much less than if the temperature of the fire box was 2500° F. If the ash had a fusing point of 2400° F. there would be no clinker in a fire box with a temperature of 2100° F., and at 2500° F., practically the same amount of clinker, the total ash being the same, as in the case of ash fusing at 2000° F. in the 2100° F. fire box. So it is a matter of relative temperatures, which explains the fact that kilns for clay goods will clinker far worse with low-temperature-fusing-ash coals than some other classes of furnaces.

Tests which have been made under boilers distinctly show the advantage of high-temperature-fusing-ash coals. Bailey reports the testing of two coals where the B. t. u. and ash were practically the same, but the fusing temperature of the ash in one was 2750° F. and in the other but 2390° F. The conditions of the test were as nearly the same as it was possible to make them. The tests showed that with the high-temperature-fusing-ash coal, with a draft of 0.22 inches, there was no difficulty in maintaining the steam pressure, while with the lower-temperature-fusing-ash coal, with a draft of 0.26 inches, there was an average lower steam pressure of five pounds, and four percent less horse power was developed.

The total amount of ash in the two coals was practically the same, but with the high-temperature-fusing-ash coal there was but 804 pounds of refuse cleaned from the grate bars (much of which was slate) and 1101 pounds from the ash pit, while with the lower-temperature-fusing-ash coal 1365 pounds of refuse were taken from the grate bars and 824 pounds from the ash pit. The clogging of the draft by the difference in the amount of accumulated material on the grate bars is obvious.

An examination of the material on the grate bars showed that but 20 percent of the high-temperature-fusing ash was clinker, while over 53 percent of the low fusing temperature ash was clinker, there being but 224 pounds from the one coal as compared with 746 pounds of the other. A further study of the size of the clinkers showed that where there were 22 square feet of grate surface obstructed in the one case there were 79

square feet obstructed in the other. The actual falling off in efficiency of the lower-temperature-fusing-ash coal as compared with the other, at the end of 18 hours firing, was 25 percent.

These facts are especially pertinent to the clay industry. Here we want, if anything, increasing efficiency. In kilns for burning clay wares the draft is limited, and at the same time it is necessary there be no lagging in the flow of the products of combustion through the kiln. It is thus clear that the clay industry requires a coal where the fusing point of the ash is high — the higher the better.

How is a proper coal to be secured? In the final analysis this is the question to be solved. As before said, a chemical analysis of a coal will not determine the fusing point of the ash, nor will an analysis of the ash itself do so. The elements present in the ash are silica, lime, magnesia, iron, alumina, sulphur, oxygen and other elements in small quantities as accidentals. The exact composition is greatly affected by the preparation the coal gets at the mine. It is supposed that the pyrites, slate, dirt, bone coal, etc., are thrown out in the mining. It is needless to say this is not done as fully as is supposed nor as paid for by the operator. It is also evident that in run of mine coal the portion of the underclay and roof which gets into the coal is not removed. It is equally evident that this source of ash varies greatly with the character of the floor and the mining practice.

It is well known that Illinois coals, for example, contain from 9 percent to 10.5 percent of ash, that is, when a mine sample is taken under standard conditions. Some of this is supposed to be thrown out in mining, so that the ash in run of mine coal should be less than 10 percent. As a fact, however, the result of extensive study shows the average ash in run of mine coal in Illinois is 15.7 percent, in the lump and in egg it is 13.5 percent, in the nut coal it is 13 percent, in the slack 17.8 percent, and it is only in the best of the washed coals that the ash content runs as low as the determinations made on samples cut from the solid in the mine. This fact shows the necessity of having more knowledge than an analysis furnished by the operator of samples cut in the standard manner.

It is a generally prevailing idea that sulphur is the cause of clinker trouble. Where the sulphur exists as pyrites, the iron present may act as a flux and cause a reduction in the fusing temperature of the ash, but, however, much the greater portion of the sulphur itself burns and leaves the furnace as a gas. There does not appear to be any relation between the sulphur content of the coal and the quantity of the clinker, or the fusing point of the ash, and one can hardly see how such could be the case.

The quantity of the ash bears no relation to the fusing temperature, and there is no apparent reason why we should so think, neither is the color of the ash an indication of the fusing properties.

It is possible, however, to buy coal with at least a relatively high fusing temperature ash. To do this intelligently it is necessary not only that the fusing point of the ash in the coal as sampled in the mine be determined, but we must know the character of the coal in this respect as received. We must also know the temperature of the fire box, and how it varies from time to time during the burn. Again, the mine should be examined to determine the uniformity of the ash content and the uniformity of the behavior of the ash, to know if certain portions of the bed should be left in mining, to learn what portion of the ash is due to mining operations, as distinguished from the ash inherent in the coal. These are but some of the factors to be determined. They cannot be determined by the purchaser sending a sample taken at random from a car to some chemist for analysis. Few coal laboratories pay any attention to the fusing point of the ash, and will not until compelled to do so.

Samples should in all cases be taken by someone conversant with the proper manner of taking coal samples, both in the mine, and in the car or stock pile. They should be taken by someone familiar with mining practices and with the peculiarities of the bed being worked. Preferably, such work should be done by some bureau or laboratory which would not represent any one particular manufacturer, but was an organization which would take up the study in the interest of all. Such an

organization would be of value to the manufacturer in case of disputes, for it would have a standing with the coal operator which no individual manufacturer or commercial analyst employed by the manufacturer could possibly have. The expense involved would be small in comparison to the benefits derived.

MODIFIED LOAD TEST FOR FIRE BRICK

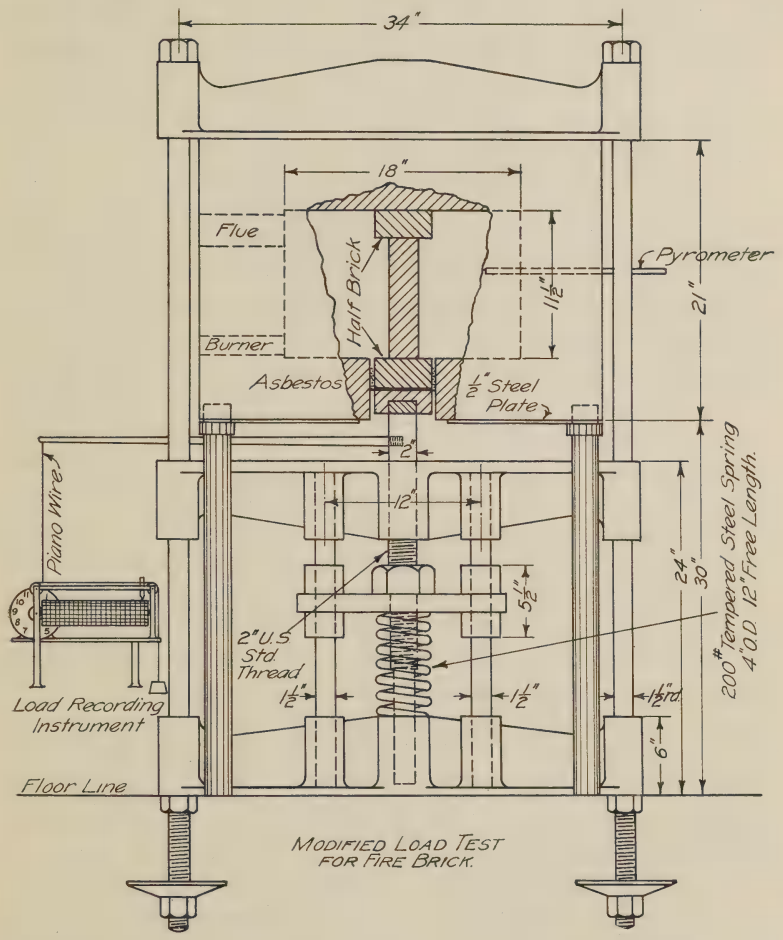
BY J. B. SHAW

At the Pittsburgh meeting of this Society in 1910, Bleininger and Brown brought forth a load test for fire brick which they had evolved after a very extensive and thorough series of experiments. They recommended the test for use in determining the ability of fire brick to stand up at furnace temperature under comparatively high loads. The test met with some criticism, as evidenced by the discussion following the paper, but its value was immediately recognized, and it has been quite generally adopted as one of the principal methods of classifying refractories. The test consists in subjecting the brick on end to a load of 50 pounds per square inch and carrying the temperature up to 1350° C. "A No. 1 fire brick should show no marked deformation and should not be shortened more than one inch for the standard 9 inch length."

While at the Pittsburgh Testing Laboratory the writer was frequently called upon to test fire brick and contemplated building a furnace for making this test, but upon careful study it was decided that some modification of it might be made to advantage. There are two points in which this test does not give all that might be desired. First, it does not admit of close comparison of high grade fire brick; second, it does not give any record of how the brick acts under test except that it stands or fails. With these points in mind, an effort was made to design an apparatus which would do all that the original one does and at the same time fill in the discrepancies mentioned, thereby enabling one to distinguish more accurately between different grades of fire brick.

The Apparatus. Figure 1. is the original design as furnished to the machinist. There were minor changes made during the construction, but in principle the machine was built as shown. For the heavy iron braces much lighter ones were substituted, but otherwise no change was made. The load-

TRANS. AM. CER. SOC. VOL. XIX FIG. 1. SHAW.



MODIFIED LOAD TEST FOR FIRE BRICK.

recording instrument was made by the machinists who built the other apparatus, starting with a dollar clock and a brass cylinder and gearing them together to give the desired speed. The outfit as built cost about $60.

The Test. The brick to be tested was accurately measured to determine the area of its cross section. Two half-bricks which had been previously heated under pressure to 1400° C. were used for bearings on the end of the brick. A thin film of fine sand was placed between the half-brick and the brick to be tested. The door (not shown) was 9 in. wide and the height equals that of the furnace chamber. The brick were placed in the furnace through the door, and the piston head brought up against the bottom half-brick by turning the nut on the top of the spring. The piston head was of steel, and between this and the bottom brick was placed a quarter-inch of sheet asbestos cut to just fit the opening in the bottom of the furnace. The space around the half brick and above the sheet asbestos was packed with asbestos fibre. In this manner the steel parts below the furnace were well protected from the heat. The brick being firmly set in place, the nut over the spring was screwed down until the desired pressure (50 pounds per square inch) was applied to the brick. For instance, a 200 pound spring being used, compressing the spring five inches would give a load of 1000 pounds on the brick. Having adjusted the load, the pencil of the recording instrument was set at zero, and any movement up or down of the piston was recorded on the co-ordinate paper wrapper around the brass cylinder. The gas burners, which used compressed air and natural gas, were lighted, and the clock on the recording instrument started at the same time. The clock lost some time (about 10 minutes during a test of five hours), and this was noted and allowed for in replotting the results on the record sheet with the temperature curve.

Comparison of Tests. In comparing this test with that of Bleininger and Brown, one essential difference will be noted, *i. e.*, in the latter the load is constant throughout, but in this new test the load decreases as the brick crushes. This may be construed as meaning that in this test the brick is able to adjust itself to its surroundings, as it always does in use in furnaces.

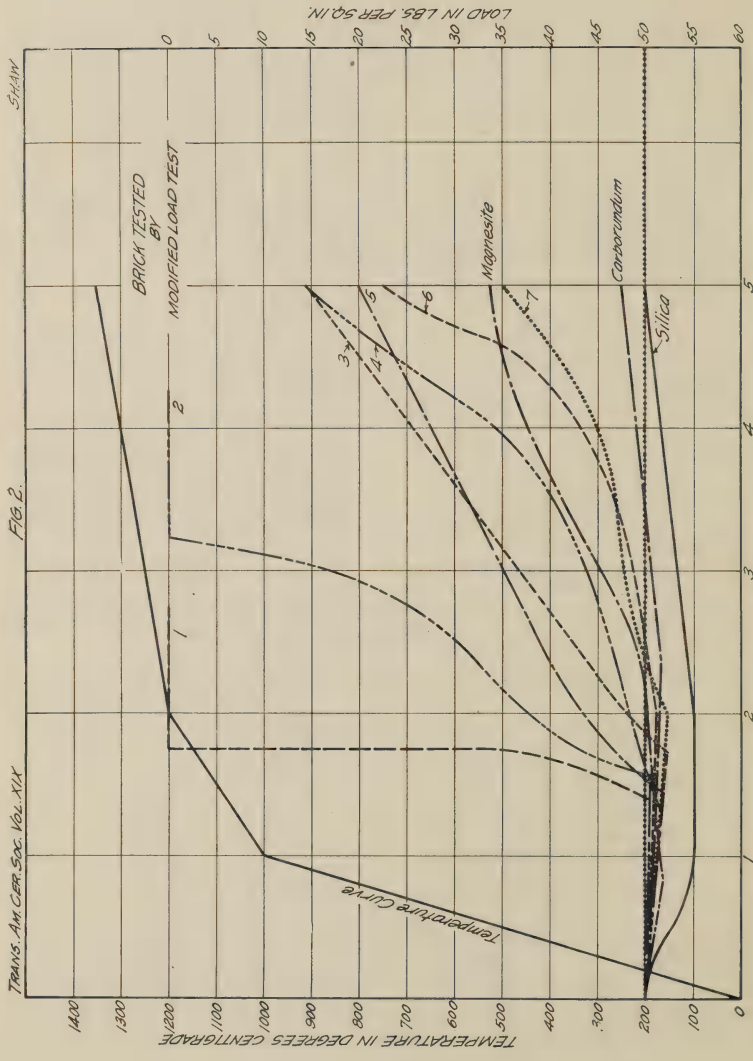
Interpreting the curves according to this idea, theoretically any point on a curve represents the load that brick is able to stand at the given temperature. This is undoubtedly true for these tests, but it is highly probable that the time factor would decrease the indicated load carrying capacity of the brick. However, the results obtained by this test seem to indicate quite plainly the relative action of different brick under similar treatment.

Results. The curves shown in Fig. 2. are the results of a few of the tests made on this machine. Numbers 1 and 2 were made by the same firm and sent in for test. Both of these brick stood above cone 32 in the regular fusion test, but their inferiority is clearly shown by the test. They were coarse grained and lacked bond clay. Both sheared off, showing the characteristic cold crushing fracture.

Numbers 3, 4, 5, 6 and 7 are No. 1 fire brick, and all retained their shape fairly well, Nos. 3 and 4 twisting somewhat. The point indicated by a load of 30 pounds per square inch would represent a decrease of approximately one inch in the length of a brick, *i. e.*, each decrease of 20 pounds per square inch represents a decrease of 1 inch in length of a brick whose cross section is 10 square inches. The magnesite, carborundum and silica brick show characteristic curves.

The silica brick shows its characteristic expansion, and it will be noted that at 1200° crushing takes place, but at no time does it show any serious deformation. The carborundum brick shows superiority here, and the writer has made other tests on these brick which show them in some cases to be highly satisfactory in resisting fluxing action of slags.

Conclusions. The writer does not wish to be understood as offering adverse criticism of the test as recommended by Bleininger and Brown. The value of their test is recognized and is too well known to admit of successful contradiction, but it is believed that the test here described does that for which it was intended, and that by it fire brick can be satisfactorily classified as to their load-carrying capacity. It is further shown that the results of this test give in mathematical terms the relative behavior of fire brick at different temperatures under load.


SHAW
FIG. 2.
TRANS. AM. CER. SOC. VOL. XIX
BRICK TESTED BY MODIFIED LOAD TEST
Temperature Curve
Magnesite
Corundum
Silica
LOAD IN LBS. PER SQ. IN.
TEMPERATURE IN DEGREES CENTIGRADE
TIME UNDER FIRE IN HOURS

Recommendation. This apparatus gives very little trouble and admits of accurate working, but experience in using it revealed certain changes which would improve its possibilities. Chief of these is that it would be improved if the apparatus were turned up side down, that is, to apply the load from the top. This would facilitate setting the brick in place in a perfectly vertical position and getting the direction of the load perfectly parallel to the long axis of the brick which is one of the essential features of a successful test. With the machine as shown, it is rather difficult to set the brick. With this modification, it is believed the apparatus will be thoroughly satisfactory.

DISCUSSION

Mr. Moore: I would like to ask how that spring is calibrated?

Mr. Shaw: You can buy those springs and do not have to calibrate them. I did calibrate this spring, but the calibration is a straight line; they make them absolutely accurate.

Mr. Moore: You do not calibrate after use over a period of time?

Mr. Shaw: Yes, it would be advisable to do so, but they will stand use for a long time before there will be any appreciable error.

Mr. Moore: Have you tried that out?

Mr. Shaw: Yes, sir.

Mr. Riddle: I would like to ask Mr. Shaw if they maintained a uniform pressure on the brick?

Mr. Shaw: I did not maintain uniform pressure; that is just the thing I aimed not to do. The thing I aimed to do was to allow the brick to adjust itself to surrounding conditions. As the brick crushed, the expansion of the spring automatically released the pressure. Those curves represent the pressure the brick will stand at a given temperature.

Mr. Riddle: What effect did the heating up and expansion of the brick have on the pressure?

Mr. Shaw: It increased the load, as the curve shows. When the brick expanded it meant an increase in the load on the brick.

Mr. Riddle: In practice that load would be constant, wouldn't it?

Mr. Shaw: No, sir, never; if you get your kiln braced up, when you increase the heat and the brick expands, the pressure is increased.

Mr. Riddle: As the brick begins to give way by fusion, the load will be just as great, then; the load won't lighten up, will it?

Mr. Shaw: Yes, sir.

Mr. Riddle: In the feather walls of a kiln?

Mr. Shaw: Yes, sir.

Mr. Riddle: I would simply like to ask Mr. Shaw if he feels that, for example you had a row of brick under pressure just under at the spring of the crown of the kiln, say at 1400 degrees, centigrade, and had 100,000 pounds load superimposed, of course equally divided on each brick; if those brick began to fail, would the pressure of the crown lighten on the brick as they failed? Of course they would all be the same grade of brick around that course and probably all would fail about the same degree.

Mr. Shaw: The very fact that it starts to fail but does not come clear down, answers that question; they do fail until they have come to some condition they can stand, and they continue to fail until the shape of the crown is changed so that other portions are brought to where they carry the load instead of the point that is being subjected to that pressure which is causing it to fail, and what I contend there is that unless there is some such change as that, the whole arch would sink in. Unless the load or temperature was decreased, the whole arch would go in.

Mr. Malm: Did Mr. Shaw make any determination as to what the percentage of expansion was at that point, at the maximum expansion? Have you any figures on that?

Mr. Shaw: The curves will show, and the paper. I did not go into detail there. The maximum expansion that I observed on the brick was in the case of the silica brick which expanded about a quarter of an inch in a nine inch length. Figuring from the spring, if the area of the brick is 10 square inches

and you have a load of 50 pounds per square inch, the total load will be 500 pounds. This is a 200 pound spring, and a compression of one-quarter inch in its length would mean an increase of 50 pounds in total load or 5 pounds per square inch on a brick with 10 square inch cross section.

DISCUSSION CONTRIBUTED AFTER READING THE PAPER

Mr. Riddle: I do not agree with Mr. Shaw in his belief that the load should be decreased as the specimen fails. In the case of a kiln crown settling he says the brick fail until they have come to some condition they can stand. It would seem to me that they fail until they have been squeezed out and the weight of the crown rests on the brick which would have not yet failed, either due to being cooler or of better grade. If all the brick are of the same grade and all fail, the pressure would be the same throughout the entire time of failure.

A better illustration might be in the case of a special setting in a kiln. A very heavy porcelain piece set on a firebrick pier. If this piece of ware was supported by nothing else but the brick, and they started to fail, it would be very unreasonable to suppose that the weight of the piece would lighten up so as to keep the brick from flattening out and letting the piece down.

Mr. Beecher: While it is true that if an individual fire brick in a furnace or other structure at elevated temperatures starts to fail it will continue to do so until its shortened dimension relieves it of part of its initial load, it should not be over-looked that this decrease in the load on one brick must be taken up by the adjacent brick unless failure of the structure occurs. Assuming that all of the bricks in the structure are of equally good quality, it is apparent that the reason for the partial failure of one brick is due to the fact that it carried a larger initial load, or is subject to an excessive local heating. One or both of these conditions can and often do obtain, for construction is never perfect nor temperatures absolutely uniform in commercial practice. In a furnace perfectly constructed in which the heat is uniformly distributed, there would not be that evidence of partial failure of a brick here and there, to which Mr. Shaw refers. These partial failures result from the more equal distribution of the load (at the maximum

temperature, of course) which is brought about by the slight softening of the brick due to heat.

Mr. Shaw's method of test is unique and makes available some interesting and useful data. It provides a better means of differentiating between low-grade fire brick than does the constant load test, insofar as there is less tendency for the sharp and sudden failure which the autographic records obtained in the last named method so often show. It would appear that a steadily decreasing load would provide better curves and allow of closer comparisons of this class of brick. On high grade brick the constant load test should differentiate more distinctly. As an example, take two bricks which under constant load deform O and ⅛ in. respectively. Other things being equal, Mr. Shaw's method would still give O deformation for the former, but would certainly show less than ⅛ in. for the latter.

The increase in load attendant upon the initial expansion of the brick which this method obtains, certainly brings the test closer to actual conditions of use. This is an important factor in the life of firebrick and Mr. Shaw has devised a very simple and unique method of making it a factor in the test.

PAVING BRICK FROM BLAST FURNACE SLAG

BY J. B. SHAW

The idea of making paving brick from furnace slag has received more or less attention for many years by those engaged in metallurgical and ceramic research. English and German patents dating back as far as 1835 deal with certain phases of the subject, and since that time a great many more patents have been taken out. This, together with the fact that our Eastern cities have used millions of these brick in their streets, has kept the subject constantly before the American steel companies and ceramists. Notwithstanding this fact, American literature contains practically nothing dealing with the subjects. The transactions of this Society contain the only work of importance on this line that has come to the writer's attention. The first article contains a description of work done by Bleininger, Brown and Kinnison. Volume XV, p. 547, and the other is by Montgomery and Burdick, Volume XVIII, p. 492. These investigators confined their work entirely to synthetic mixtures in the laboratory, but the results obtained were of considerable importance in that they showed the possibilities of such mixtures and stimulated thought on the subject.

The apparent dearth of literature on this subject would naturally lead to the conclusion that it is of small importance and consequently has received little attention. The first of these conclusions is entirely wrong, the second is true in a certain sense. A great amount of work has been done on the problem, but it has been neither skillful nor thorough.

As regards the importance of this problem a few figures will be enlightening. Taking Mr. Unger's statement, Vol. XVIII, p. 911 for the quantity of slag produced in the United States, there is something like 16,000,000 tons annually. This is based on 33,000,000 tons of pig iron and would be at least low enough. Clinton furnaces in 1914 were producing 300 tons of slag per 450 tons pig iron. Slag block, the size of clay paving block,

weigh from 13 to 14 pounds each or 7 tons per 1,000 blocks. This shows enough slag produced to make two million thousand paving blocks and leaves two million tons for cement which would probably supply present demands for such purposes.

As to the quality of paving brick made from blast furnace slag Professor Orton has testified (Vol. XVIII, p. 911), and any one seeking further proof needs only to journey to Washington or Baltimore and see bricks in the street that have been there for many years with no signs of wear except to have the corners rounded. The writer has made rattler tests on these brick and these tests bear out Professor Orton's statement. The rattler loss will average 10 to 12 percent.

The price paid for these brick in 1915 was $35.00 and up per thousand. At this rate the steel companies are throwing over the dump every year slag which if it could be converted into paving brick would yield a gross income of 70 million dollars. Another item of no small importance enters here, namely the fact that the steel companies are paying good money to get rid of this slag. In many districts, notably Pittsburgh, the blast furnaces are cramped for room, and there being no place to dump the slag near the furnace, the railroads haul it away. In past years they have been glad to get it for filling and ballast, but the need for it has practically disappeared, and they have placed a charge of 20 cents per ton for disposing of it. The interstate commerce commission was asked for a ruling on the subject, but the writer has not learned how they ruled. This does not apply to all furnaces, many of them having ground near the plant where they dump their slag, but even this is no small item of expense, and it would seem not unreasonable to assume that the slag made is costing 10 cents per ton in order to get rid of it. Adding this to the above, the steel companies are short 71½ million dollars. Assuming the price of these brick would drop 50 percent, there is still a gross income of 36½ million dollars possible annually.

No figures are available on the cost of making these brick abroad, but the writer has figured costs from processes used in England and also from processes he has evolved in America, and the maximum figure obtained was less than $7.00 per 1,000, assuming the slag free. This figure is high, and it is probable

that the brick can be made for $5.00 per thousand. Taking $7.00 per 1,000 for cost and $17.50 per 1,000 for selling price, the net profit would be 22½ million dollars. One blast furnace making 280 tons of slag per day would net $178,000.00 annually. These figures should be sufficient to convince one of the importance of the proposition.

Previous Work. It would be surprising if a proposition of this size should escape the attention of the steel companies, especially in view of the fact that there has been many efforts to utilize the slag in other ways. The fact is that the problem has been continually under investigation at different blast furnaces. The investigators have been chemists and foremen and ordinary laborers, and as stated above, the work has been neither skillful nor thorough. The writer has visited many blast furnaces in the United States, and there are few of them where an effort has not been made by someone to make brick from slag. All efforts of which the writer has learned have resulted in failure; but if all of the investigators who have worked on this problem had given the results of their labors to the world, there would be voluminous literature on the subject, and the proper solution would have been reached long before this.

There have been two reasons why the results of these investigations have been lost. First, the feeling that the work was worthless because the result sought was not obtained. Second, the policy of keeping secret such work in the hope of ultimate success and patent protection. However, there is some literature extant on this subject, the English and United States patent offices containing sufficient "information" to enable one to get a fair idea of it. In Volume XVIII, pp. 10-911, Mr. Montgomery suggests that slag from pig-iron furnaces is not suitable for making brick, and Mr. Unger substantiates the claim by adding that brick made from American slags are very brittle. This will be shown to be not in accordance with the facts.

The writer's attention was attracted to this problem by the work of Bleininger, Brown and Kinnison, cited above. The field seemed to offer great possibilities, and therefore an effort was made to find someone who was willing to spend some money on the problem and at the same time could secure proper facil-

ities for its solution. This meant access to blast furnaces with liberty to do whatever became necessary as the work progressed. The desired combination was found in the Birmingham Slag Co. of Birmingham, Alabama, who controlled a large part of the cold slag in that district and had been working on the problem for some time.

LABORATORY WORK

Before going south some preliminary work was done at the Pittsburgh Testing Laboratory. A number of blast furnaces were visited around the Pittsburgh district, and it was found that there was nearly always someone around the plant who had some first-hand knowledge of the problem. The information obtained from these men was to the effect that brick could not be made from their slag because it was too low in alumina.

Referring to Tables I and II, the first three slags are given by Dr. Passua, Stahl und Eisen, 1910, as representing the two types of slag, glassy and stony. A study of the empirical formula (figured by the writer from the analysis) would lead the ceramist to conclude that the difference in physical structure is not due to chemical make-up but rather to the cooling treatment. Anyone of these three slags can be made glassy or stony by adjusting the rate of cooling.

Comparing Nos. 4, 5 and 6 with Nos. 8, 9 and 10 it will be seen that the slags of the Pittsburg district are very similar to those of the Birmingham district.

The English brick stands in a class by itself chemically, being distinctly higher in alumina and lower in lime than any slag shown here. So far as the writer has been able to learn, there is only one slag made in the United States that is similar to the English slag, such a slag is being made at the Sparrows Plant of Pennsylvania Steel Co. (now controlled by Bethlehem Steel Co.) No analysis of this slag is available, but the writer has seen analyses of it and knows it to run from 22 to 28 percent alumina. The ore used at this plant comes from Cuba.

With this information at hand, the following mixtures were melted, in order to get an idea of the possibility of remelting the slag and making addition to it to obtain the desired product.

The slag used was ground to a fine powder, and the additions made in powdered form using pure materials. Two hundred gram batches were melted in a small gas-fired furnace using fire clay crucibles.

CARRIE FURNACE SLAG

NO.	GRAMS SLAG	SiO_2	Al_2O_3	$CaCO_3$	$MgCO_3$
1	100	5	....	....	....
2	100	10	....	....	....
3	100	....	7.5	....	....
4	100	....	15.0	....	....
5	100	....	7.5	9	....
6	100	....	15.0	9	....
7	100	....	7.5	....	12
8	100	....	15.0	....	12
9	100	....	....	....	....

These were melted at 1300° to 1350° C. and poured out into molds when sufficiently fluid. No great difference in fluidity or fusibility was observed except in the case of Numbers 5 and 6, neither of which would pour out of the crucible at the temperature.

All these mixtures, when poured into molds and cooled rapidly to atmospheric temperature, are glassy throughout. Samples of each were replaced in the furnace and heated up to 1000° C, the fire turned out, and the furnace cooled to atmospheric temperature in 10 hours.

Results. Nos. 1 and 3. Deformed at 1000°C.

No. 1. Black and stony throughout.

No. 2. Black glass with a few small crystals.

No. 3. Light gray and highly crystalline but less so than No. 1.

No. 4. Glassy with considerable crystalline matter.

Nos. 5 and 6. Stony, not melted.

No. 7. Glass throughout.

No. 8. Glassy with a few crystals in the mass.

No. 9. Glassy with a few crystals in the mass.

This series indicates:

1st. That the physical structure of the product is greatly affected by the composition and the rate of cooling.

2nd. SiO_2 can be added to the slag and still get a stony structure.

3rd. Moderate addition of Al_2O_3 acts very much like a similar addition of SiO_2, but a high percentage of either seems to retard crystallization.

4th. Addition of lime makes the slag very much more refractory, but the same equivalent amount of $MgCO_3$ does not materially affect the fusibility.

5th. The results indicate that any of these could be converted to stony structure by proper annealing.

Another series was melted in the same manner as the above using Clinton furnace slag. The formula shows this series to cover quite a wide area although a few mixtures were made. SiO_2 and Al_2O_3 vary independently and also together in high lime series, and independently in the magnesia series.

CLINTON FURNACE SLAG

NO.	SLAG	CHINA CLAY	$MgCO_3$	SiO_2
	grams	*grams*	*grams*	*grams*
1	100	13	0	0
2	100	26	0	0
3	100	39	0	0
4	100	0	0	6
5	100	0	0	12
6	100	0	0	18
7	100	70	60	0
8	100	70	60	10
9	100	70	60	20
10	100	0	60	30
11	100	0	60	40
12	100	0	60	50

FORMULAE

NO.	CaO	MgO	(Al_2O_3+Fe_2O_3)	SiO_2
1	90	10	.19	.70
2	90	10	.24	.80
3	90	10	.29	.90
4	9	10	.14	.70
5	90	10	.14	.80
6	90	10	.14	.90
7	52.6	47.4	.24	.68
8	52.6	47.4	.24	.78
9	52.6	47.4	.24	.88
10	52.6	47.4	.08	.64
11	52.6	47.4	.08	.74
12	52.6	47.4	.08	.84

Results. This series was melted exactly as the preceding. When poured and allowed to cool rapidly to atmospheric temperature, all are glassy, practically no crystallization. When annealed in the furnace as described above all show some crystallization.

Nos. 9 and 12. Entirely crystalline.

Nos. 3 and 6. Almost entirely crystalline.

Nos. 8 and 11. Almost entirely crystalline, about like Nos. 3 and 6.

Nos. 2 and 5. Largely glass but some crystals.

Nos. 7 and 10. Largely glass but some crystals.

Nos. 1 and 4. Almost entirely glass with a few crystals.

This series indicates:

1st. Increasing SiO_2 content of this slag promotes crystallization on cooling.

2nd. The magnesium slags crystallize more readily than those low in MgO and high in lime.

3rd. High Al_2O_3 has not increased the amount of crystals, but there is a distinct and very important difference between the crystals in the high and low Al_2O_3 slags. In those high in Al_2O_3 they are very small and granular. Numbers 10, 11 and 12 where crystalline, have a stony fracture looking much like the English brick or a limestone, while Nos. 7, 8 and 9 are coarsely crystalline. This indicates that the Al_2O_3 performs an

important function in determining the crystalline structure of the product.

It was desired to pursue this line of investigation farther, but time would not permit. However, the chief information sought had been obtained, the two series having shown that a very great variety of products can be obtained from the same slag by making reasonable modifications in its composition and varying the heat treatment. The melting temperature will be from 1300°C. to 1400°C., and the furnace linings will be very rapidly destroyed.

WORK AT THE BLAST FURNACE

At this point the scene of operations was shifted to Birmingham, and hot slag direct from the blast furnace was used. A furnace was built similar to the enameler's frit furnace, of 100 pounds capacity. Kerosene oil was used as fuel burned with steam blast. No difficulty was experienced in getting sufficiently high temperatures, but it was expensive fuel. The furnace was built up near the blast furnace where slag could be ladled out of the runners as it flowed to the slag pots and poured directly into the frit furnace.

Charging the Furnace. Since it was necessary to handle the slag while in the molten state it was not possible to do very accurate weighing, and some scheme had to be devised whereby the quantity of slag used could be measured. A ladle of 20-pound capacity was used, but it was not possible to handle this quantity neither was it possible to pour all the slag out when it was full, because of the crust forming on the edge. After a few trials of dipping a convenient amount to handle and pouring and weighing, it was found that a fair estimate could be made of the quantity of slag poured. The error would not exceed 10 per-cent, and inaccurate as this was, it seemed the only practical method of working and therefore was adopted.

The furnace was heated up to 1200°C. before charging, and when the slag came down the runner from the blast furnace it was ladled out and poured into the frit furnace. The addition of raw material was made while pouring the slag into the furnace.

Melting. The addition of any of the raw materials used set up a vigorous reaction causing the batch to boil vigorously for a few minutes, but it soon settled down to quiet fusion, and at no time was more than 30 minutes required, after charging the furnace, to get the charge ready to cast. The charge used was usually 50 pounds of slag plus the raw materials.

Casting. When the charge was ready to cast, the molds were set under the spout of the furnace and on rollers so that when one mold was full the next could be pulled into position under the spout; the slag continued to flow until all was out of the furnace. At this point it should be said that three different furnaces were built before a single brick was cast. The first one of the frit furnace type had a deep chamber 2 ft. by 2 ft. by 6 in. When the slag was ready to cast and the plug knocked out, the hole promptly filled up with congealed slag, and no amount of heat in the furnace would induce the slag to run out of it. After dipping the slag out to leave a depth of only 1 or 2 inches on the bottom, it could be induced to flow. This furnace was remodeled making a long narrow chamber 4 ft. by 1 ft. by 4 in. This was some better but not satisfactory. The next and last furnace was made with a chamber 8 in. deep at one end and tapering up to zero at the tap hole. It was 18 in. wide by 2 ft. long. The furnace was pivoted so it could be tilted when ready to pour. This worked very satisfactorily. The reason for these failures was the assumption that slag could be handled like glass or enamels. They also indicate quite plainly that the fuel bill in melting slag will be much greater than in melting either glass or enamel.

Annealing. The annealing furnace was made of convenient size to hold 50 or 60 brick, and was heated with coal. It was a semi-muffle with a chamber 12 in by 12 in. by 4 ft. long. This also was the outgrowth of a number of different types which had failed to give desired results. These are mentioned later.

Modifications of Slag. The slag made during the first experiments was No. 8, Tables I and II. Additions of 5, 10 and 15 and 20 percent of silica were made in the form of clean sand. The effect produced on the fluidity of the slag was not

great, but the character of the finished product was distinctly different. The high silica product was more easily annealed to a tough brick, but by properly adjusting the annealing treatment, that is, time and temperature, all of these mixtures were converted into fairly tough brick.

Additions of iron oxide to the slag in amounts of 5, 10, 15 and 20 percent were now made. It was thought that iron oxide would probably act similar to alumina. The effect of iron oxide on the fusibility of the slag is very marked, all additions up to 20 percent increasing fusibility and making the slag flow at comparatively low temperature. Furthermore the iron oxide does make the finished product very tough and easily annealed into a satisfactory product.

Mixtures of iron oxide and silica, half and half, were now added to the slag in amounts of 5, 10, 15 and 20 percent. The result here is similar to that obtained by using iron oxide alone. The brick have a wide range of annealing treatment in which good products can be obtained. One great objection to this product is its color. Obviously the brick will be black, a fact which makes it objectionable. The toughest brick by this method was made by adding 10 percent Fe_2O_3+10 percent SiO_2 to the slag. These brick were fully as tough as any English brick the writer has tested. No rattler test was made on them, but they were tested with a hammer along with English brick and shale paving brick. Although accurate comparison in mathematical terms cannot be made by this method, it is easily possible to distinguish between good and bad, tough and brittle.

Experiments and results up to this point led to the conclusion that the product obtained depends more upon the annealing treatment than on the composition of the slag. It has been shown that the question whether the product will be glassy or stony depends upon the annealing treatment. This condition continues to govern the nature of the product after it has received proper treatment to give it a stony fracture. It is not difficult to obtain a stony structure, but the problem of getting a tough stony product rather than a brittle one is where the secret of the whole matter lies.

It was further concluded as a result of the work so far done that it is possible to make a good product by modifying the

composition of the slag, but the economic value of the process is very doubtful. The fuel required even when the slag is obtained in the molten state will be very high, and furthermore it would be practically impossible to maintain refractory furnaces for such a process. In view of these facts, the line of investigation was changed entirely. The problem resolved itself into one of taking the slag as it came from the blast furnace and making a brick of it without any change. This is the method used in England and which has been tried so often in America with failure.

Brick From Slag Alone. Attention was now focused upon the problem of so treating the slag after casting as to convert it into a tough brick. The slag was dipped from the runner and poured direct into the brick molds. The resulting bricks were annealed by various methods and in various types of furnaces. The method of piling the hot brick in a furnace and allowing to cool slowly, which is used in England, was tried without success. This furnace was heated to 900°C. before charging with brick and then cooled to atmospheric temperature at various rates requiring from 5 hours to 60 hours but no good brick were obtained. All were brittle, and most of them broken to pieces. Another result of this treatment was to granulate the slag on the surface, sometimes penetrating to the center of the brick, giving a brick when cold that weighed less than one pound. (The French sometimes granulate their slag by blowing a blast of cold air against it instead of cold water.)

The next step was to bury the brick in sand (as described in many patents) and allow them to cool there. This gives good results on English slags, but it can be made to give results on American slags only by absolute control of the rate of cooling. It was adopted and used very satisfactorily. Of the brick obtained by this process some would fall to small fragments when cold, others had cracks penetrating some distance but would stand some hammering. Some perfectly sound when cold, showing very tough, when allowed to stand for 4 days would then begin to dust, just like Portland cement clinker and in a day or two would be nothing but in impalpable powder. But many were made that were as tough as the English brick. Slags Nos. 9 and 10 are analyses made from two brick, one of which dusted

to a fine powder, the other (No. 9) was still sound and tough when last seen by the writer, several months after making.

TABLE I.

NO.	CaO	MgO	$(Al_2O_3+Fe_2O_3)$	SiO_2	S	CaS	$CaSO_4$
	percent	*percent*	*percent*	*percent*	*percent*	*percent*	*percent*
1	45.54	4.23	12.47	33.25	....	4.91	.08
2	50.11	1.19	13.53	31.08	....	4.17	.48
3	45.96	4.34	12.35	32.36	....	5.51	.73
4	36–42	1–8	12–14	28–36	1–2	....	....
5	42.	3.	15.	33.	2.	....	....
6	40.	....	13.41	34.	....	....	....
7	34.76	5.44	27.40	32.40	....	....	....
8	42.53	8.89	12.05	35.40	1.16	....	....
9	44.94	1.40	16.32	36.52	1.35	....	....
10	46.68	1.30	17.40	34.16	1.27	....	....

TABLE II.

NO.	Eq. CaO	Eq. MgO	Eq. $(Fe_2O_3+Al_2O_3)$	Eq. SiO_2	REMARKS	AUTHORITIES
1	.86	.14	.12	.54	glassy	Dr. Passua Stahl und Eisen.
2	.97	.03	.13	.53	stony	Dr. Passua Stahl und Eisen.
3	.89	.11	.12	.54	stony	Dr. Passua Stahl und Eisen.
4	....	....	.....	....	P. T. L.,	
5	.91	.09	.18	.67	Clinton, Furnace, Pgh.	P. T. L.,
6	....	....	.....	....	Carrie Furnace, Pgh.	
7	.85	.17	.36	.72	English Slag Brick,	P. T. L.,
8	.77	.22	.10	.60	Ensley Ala. Ensley, Ala.	T. C. I. & R. Co. David Hancock, Birmingham, Ala.
9	.96	.04	.19	.74	Sound Brick	
10	.965	.035	.19	.65	Dusted Brick	David Hancock, Birmingham, Ala.

P. T. L. = Pittsburgh Testing Laboratory.

Having repeatedly made good tough brick from both types of Birmingham slag, it was concluded that the Pittsburgh slag would offer no insurmountable difficulty, as they are similar to those in the Birmingham district. The Sparrows Point slag, mentioned above, being radically different from these slags, the scene of operations was shifted to that plant. No difficulty was encountered here. In just ten days after arriving on the plant a furnace was built, a set of molds made and a set of six brick turned out which were pronounced O. K. by all who inspected them.

SUMMARY

It is not claimed that the last word has been said here on this problem, neither is it claimed that everything has been learned that is to be known about the problem. The work outlined here only covered a period of six months, and much of that time was spent in building furnaces. But it is claimed that the possibility of using American slags for making paving brick has been proven without the possibility of a doubt.

It has been shown further that these slags can be modified by the use of iron oxide and made into good tough brick, but these will be black brick which is an objectionable feature. The work could be done in something like tank furnaces for melting glass, but the process would be very costly and of doubtful economic value.

The melting of the cold slag, millions of tons of which are available is out of the question.

The Future of Slag Brick. This question is of very serious import to the manufacturers of clay paving brick. That the slag now being wasted will be converted into paving brick in the future seems to the writer certain. The cost of making them will not exceed $7.00 per 1000 and probably not $5.00 per 1000. How soon this will come depends entirely upon the steel companies and the future economic condition of the steel business. The question rests entirely with the companies which control the slag. No independent company would be justified in starting this business unless they could monopolize a very large amount of slag, for competition of the steel companies would immediately follow with disastrous results.

But the time will come when the steel companies will find it necessary to utilize their slag. The European war will not last forever, and dull times are sure to come for the steel business, and when that comes slag brick will be made. The fact that it has not already been done is one of the indications of great profits and resultant wastefulness of the steel business in the United States.

Rattler Test. Figure 1 shows the result of a test made on the section from the end of a brick made from slag No. 8. The brick was made in May, 1915, and the test made in February, 1917. No apparatus was available for making these tests where the brick were made, and when opportunity was found for testing, all samples had disappeared except some small fragments not large enough to give satisfactory tests.

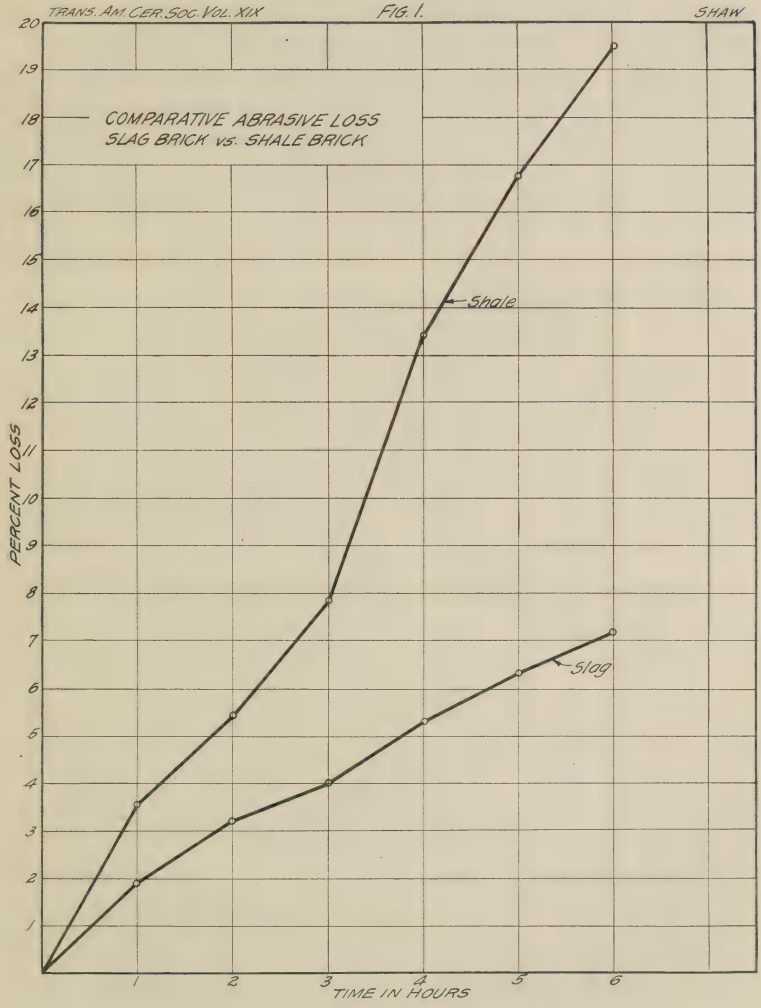
The test made was substantially the same as that made by Montgomery and Burdick. In fact the same ball mill was used. The shale block was a well vitrified block of well known make. All edges were rounded on the emery wheel before testing, and the briquettes were weighed every hour.

The curve shows that this slag block is not only superior to shale block, but that it ranks well with the English slag block. Assuming that the shale block would lose 25 percent in the standard rattler, this slag block would lose about 8 percent figured on the basis of the test.

DISCUSSION

Mr. Orton: I would like to ask Mr. Shaw if he would mind giving us a statement of what the annealing conditions are that he finds necessary to develop good structure? I had a couple of boys work on a slag thesis some years ago and we reached the same conclusion.

Mr. Shaw: As I said, I have not learned all about it yet, but I have learned enough to convince me that it is easily possible —in the annealing of these bricks in England they throw them into a kiln and let the kiln cool gradually. That will not work on American slag. I have tried that method as outlined in the paper. I did not go into it in detail, but the reason for failure is that the atmosphere granulates American slag. The French gran-


TRANS. AM. CER. SOC. VOL. XIX
FIG. 1.
SHAW
COMPARATIVE ABRASIVE LOSS
SLAG BRICK vs. SHALE BRICK
Shale
Slag
PERCENT LOSS
TIME IN HOURS
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

ulate their slag very often by blowing a stream of cold air against it instead of cold water, and that is what happens when you try to make brick from American slag by the English method. It is necessary to anneal them where the air does not come in contact with them, and to catch them at the right temperaure and not allow them to cool below a certain critical point suddenly. In other words, it is necessary to put the brick into a furnace, the temperature of which is the softening temperature of the brick, and hold the brick at that temperature until it has become uniform from inside to out, otherwise a hard crust will form on the outside.

AN INSTRUMENT FOR MEASURING PLASTICITY

BY WARREN E. EMLEY

Plasticity is one of the main factors in determining the value of a lime. It is, therefore, imperative that the lime industry be provided with a means of measuring plasticity. For several years past, the Bureau has been studying this question, with an idea of designing an instrument which would do the work. The progress of this study can be followed in detail by reference to the following papers:

The Plunger Viscosimeter (Results of Testing Lime).
Trans. Nat'l Lime Mfrs. Assn. — 1913.

The Clark Viscosimeter.
Trans. Amer. Ceramic Society — 1913.

The Compressive Method of Measuring Plasticity.
Trans. Nat'l Lime Mfrs. Assn. — 1915.

Deformation of Plastic Bodies Under Compression as a Measure of Their Plasticity.
Trans. Amer. Ceramic Society — 1915.

The Compressive Method of Measuring Plasticity.
Trans. Nat'l Lime Mfrs. Assn. — 1916.

Method for Measuring the Working Quality of Lime Mortars.
Trans. Nat'l Lime Mfrs. Assn. — 1916.

As a result of this extended investigation, we have arrived at a clearer conception of the meaning of plasticity, at least as applied to wall plasters. If this conception is correct, then the machine which we now bring to your attention is theoretically sound. The work which has been done with it shows that its results are correct from a practical viewpoint.

The final word in judging the plasticity of a wall plaster is always left to the man with the trowel. The idea was conceived that if the man could be replaced by a machine so designed that the forces actuating the trowel could be measured, that the rela-

tive magnitudes of these forces would be indicative of the plasticity of the material. Instead of moving the trowel over the plaster, it was found mechanically simpler to design a machine which would move the plaster over the trowel, the results, of course, being the same in either case.

When spreading a plaster on a wall, the trowel is so held that it makes an angle of 10° to 15° with the plane of the wall. The force applied to the trowel is thereby divided into two components, one acting parallel to the wall — the other acting normal to it.

In this instrument, the trowel is represented by a conical disk, which is mounted point downwards on a vertical shaft. The side of the cone makes an angle of 10° with the horizontal, corresponding to the angle between the trowel and the wall.

The wall is represented by a disk of plaster of Paris of known absorption. It is mounted on the upper end of a vertical shaft, directly below and concentric with the cone. This shaft is threaded and runs thru a fixed nut. As the shaft revolves, the wall (or disk) is forced against the trowel (or cone) with a spiral motion. It presses vertically upwards against the cone in a manner analogous to that component of the force exerted by the trowel which acts normal to the wall. The turning motion moves the disk over the face of the cone bringing into play that component of the force which is parallel to the wall.

The cone is so mounted that either of these forces is able to cause motion independently of the other. Any motion of the cone is transmitted thru a system of levers to one of two bars, which are suspended like pendulums, and causes the bar to swing out of its originally vertical position. The greater the angle through which the bar is moved, the greater will be the force of gravity tending to return it and the cone to their original positions. It follows, therefore, that if a constant force tends to cause motion of the cone, the bar will swing out until the force of gravity acting on the bar is in equilibrium with the force acting on the cone. When this condition has been attained, both the cone and the bar become stationary, and the force acting on the cone is directly proportional to the

sine of the angle thru which the bar has moved. The bars are graduated and provided with bobs which can be moved up or down thus decreasing or increasing the force required to produce a given angular deflection.

Calculating from the dimensions of the instrument as at present designed, we find the following relations.

$v = 1.6 + 27.42 \sin a + 4.65\ l \sin a.$

$t = 9.29 \sin a + 1.577\ l \sin a.$

$v =$ vertical force acting on cone, in grams per sq. cm.

$t =$ tangential force acting on cone, in grams per sq. cm.

$a =$ angle which the respective bar makes with vertical.

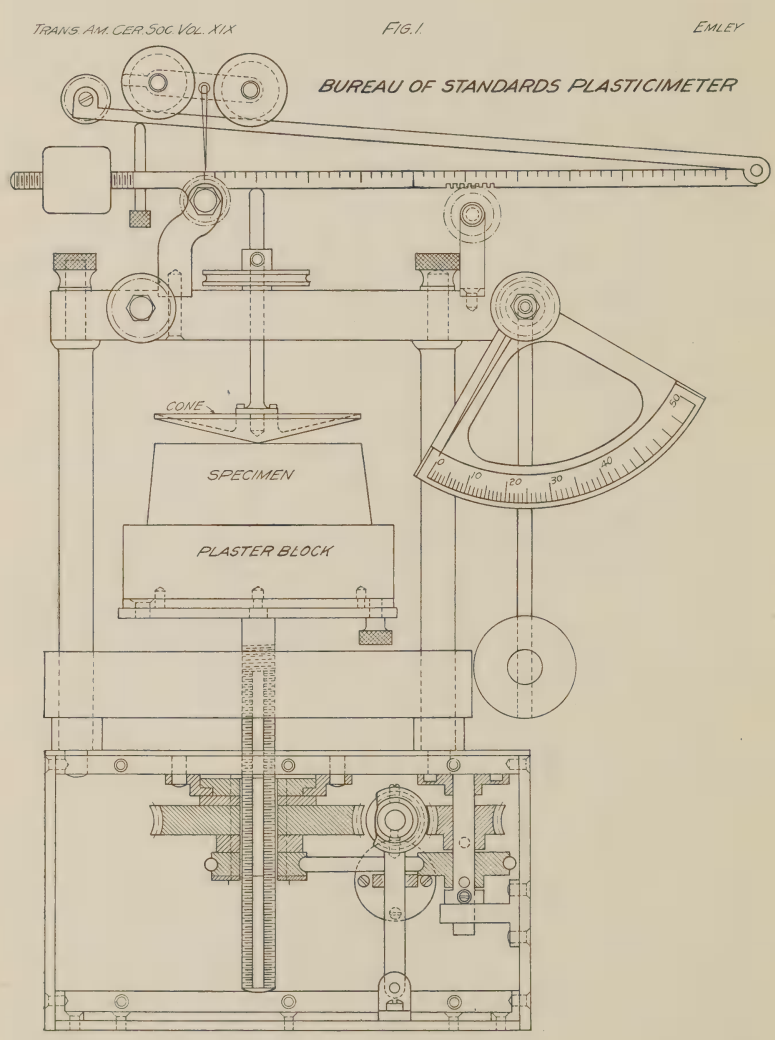
$l =$ distance from point of support of bar to top of bob, in cms.

The independent term in the first equation is caused by the weight of the cone itself.

If a sample of plaster is molded on the disk, and is driven against the cone at a constant speed, the two bars will assume definite positions. From these positions, the two forces acting on the sample may be calculated by means of the above formulae. The vertical force corresponds to that component of the force actuating a trowel, which is normal to the wall, the tangential force corresponds to the component parallel to the wall. The machine is, therefore, capable of measuring independently the different forces which are applied to a trowel.

In the first series of experiments, the disk was made of non-absorbent material, *i. e.*, plaster of Paris boiled in paraffin. The behavior of a sample on this surface is analogous to the application of a scratch coat on burned clay tile.

The first question which arose was "what consistency shall be used?" A number of samples of a lime mortar were made up to different consistencies and tested, and the tangential forces were plotted against the vertical forces. It was found, as was to be expected, that the thicker the paste the greater were the values of both forces. It was entirely unexpected, however, to find that, as the consistency became thicker, both forces increased in the same proportion, so that the ratio between them is a constant and is independent of the consistency.


TRANS. AM. CER. SOC. VOL. XIX
FIG. 1.
EMLEY
BUREAU OF STANDARDS PLASTICIMETER
CONE
SPECIMEN
PLASTER BLOCK
0
10
20
30
40
50

This ratio of tangential force divided by vertical force corresponds to $\frac{\text{force parallel to the surface,}}{\text{force normal to the surface}}$ and is, by definition, the coefficient of friction. It follows, therefore, that the coefficient of friction between the trowel and the plaster is independent of the consistency of the plaster (on a non-absorbent surface). When using the machine, it is not necessary to make up the sample to any definite consistency; it is necessary only that the consistency be such that readings can be taken on both the vertical and tangential forces at the same time.

From the above reasoning, it will be seen that if the ratio of the $\frac{\text{tangential force}}{\text{vertical force}}$ is high, the material is sticky. These ratios, for neat lime pastes, are found to run from about 1.00 for the most plastic to about 1.50 for the stickiest.

It has long been known to the trade that a sticky lime can be improved by the addition of sand. Experiments with this machine show that the addition of increasing proportions of sand causes a regular decrease in the value of the coefficient of friction, and hence, in the stickiness. A sticky lime, having a coefficient of 1.50 for the neat paste will require the addition of about five parts of sand to reduce this coefficient to 1.00.

Obviously, this is a logical definition of the sand carrying capacity of a lime. It is necessary only to decide that a mortar for a given purpose shall have a certain definite coefficient of friction. A few experiments with the machine will determine accurately how much sand must be added to a given lime to produce a mortar of the required coefficient. This proportion of sand may be designated the sand carrying capacity of the lime. Since it depends upon the plasticity of the mortar, this definition is in closer agreement with practice than those heretofore put forth which used the strength of the mortar as the criterion.

It is apparent that the quantity of sand which must be added to a given lime to produce a mortar of a given coefficient will depend upon the quality of the sand. By the use of a standard lime, it is perfectly possible to reverse the above

process and measure the lime-carrying capacity of different sands. This will give definite information as to the comparative values of sands for plastering purposes.

The above line of reasoning is true only when the plaster is applied to a non-absorbent surface. When the plaster is used for either the brown or the finish coat, the absorptive power of the base coat must be considered. That is to say, a lime may be beautifully plastic when used as a scratch coat on vitrified tile, but when an attempt is made to follow up with a brown coat of the same material, it may be found that the scratch coat will suck the water out of the brown coat so rapidly that the latter cannot be worked at all.

The absorbent surface is represented in the machine by a plaster of Paris disk without the paraffin. A sample molded on such a disk is found to behave quite differently than it would on a non-absorbent surface. Both the vertical and tangential forces are functions of the time, because the sample is constantly losing water to the disk, its consistency is growing continuously thicker, and the forces larger. The vertical force increases nearly as a straight line function of the time (at least with lime mortars). This is because the layer of material in contact with the disk loses its water and adheres strongly to the disk. This prevents the specimen from spreading out laterally, and hence from any measurable deformation vertically. The specimen is to all intents a rigid body, which transmits the vertical movement of the disk undiminished to the cone. With the tangential force, however, the case is different. This has to do with the motion of the cone over the upper surface of the specimen, whereas the suction of the disk is applied to the lower surface. An increase in the tangential force will be caused by a thickening of the consistency of that layer of material which is in direct contact with the cone, and this is dependent upon the rapidity with which water can percolate from this layer, through the specimen, into the disk. When testing limes noted for their plasticity, it was found that the tangential force remained constant for from three to five minutes; with a non-plastic lime, the tangential force is nearly a direct function of the time. These results are

in perfect accord with practical experience. The rapid drying of the plastic limes may be a little extreme, but this is caused by the very high absorptive power of the disk used. In order to obtain comparable results, it is necessary that the absorptive power of the disk be always the same, but its value is immaterial.

It will be noted from the above that while the vertical force varies directly as the time, the tangential force does not. Their ratio is, therefore, not a constant, and cannot be used as a measure of the plasticity of the material on an absorbent surface as it could on a non-absorbent surface. Both the experimental evidence and the reasoning show that the machine is able to distinguish between materials of different degrees of plasticity when applied to an absorbent surface. It remains merely to find some convenient method of expressing the results so that they can be readily recorded and compared.

The tangential and the vertical forces acting at any given time are known. If the machine is run at a constant speed, the distance through which these forces act is directly proportional to the time. Suppose, for example, we plot the tangential force (as ordinate) against the time (as abscissa) an actual measurement of the speed of the machine shows that this tangential force acts thru a distance of 25.94 cms. per minute. If, therefore, the abscissæ scale on the above curve is multiplied by 25.94, it will read "distance in centimeters" instead of "time in minutes," without any change in the shape or position of the curve. Any two ordinates may be erected, indicating the beginning and end of a certain interval of time. The area enclosed between these two ordinates, and under the curve, is the product of the force times the distance thru which it acts, and is, therefore, the work done during the selected interval of time, by the tangential force.

The work done by the vertical force can be determined in an analogous manner. This force, however, acts thru a distance of only .635 cms. per minute, so that the work done by it is very small when compared with that done by the tangential force in the same length of time (provided, of course, that the forces are nearly equal).

There is also a third force, acting perpendicular to both of the others, which causes the lateral spread of the specimen. In magnitude, this force is equal to the vertical force multiplied by tan $10° = .176\ v$. Its rate of action is about 1.18 cms. per minute.

During any interval of time, the total work done is the sum of the work done by the tangential, the vertical, and the horizontal forces. The work done by the tangential force is generally 90 percent or more of the total, so that the other two may be neglected for ordinary experiments. The relative magnitudes of these quantities of work depend upon the design of the machine, and the above figures must be revised if any change is made in the speed of the machine, the pitch of the screw, or the diameter or angle of the cone. The quantities of work found may be expressed in ergs by multiplying them by $\frac{980}{60}$

The calculations can be decidedly simplified if we agree to consider only the tangential force, and if we adopt a standard interval of time, say three minutes. Under these circumstances, the horizontal dimension of the area representing the work is a constant. The average vertical dimension is the average value of the tangential force. The area or the work done, is therefore, directly proportional to the vertical dimension, or the tangential force. It is, therefore, necessary to measure the tangential force at, say, half minute intervals, and to find its average value during three minutes. The smaller this force, the less work required, and the more plastic the material. For that material is the most plastic which can be spread out on a given surface in a given length of time with the least work.

The average value of the tangential force during three minutes may be designated the plasticity figure for the lime on an absorbent surface — the smaller this figure, the more plastic the lime. Since the tangential force varies more or less with the time, depending upon the rapidity with which the sample dries out, it is necessary to specify which three minutes shall be selected for the observations. Assume two samples of the

same lime made up to different consistencies. Test the thicker one first, and plot the tangential force against the time. Then test the thinner one. It is found that a certain interval of time is required for the disk to absorb the excess water from the thinner paste, after which both pastes behave the same. That is, a variation of consistency will cause the force-time curve to shift its position in a direction parallel to the time axis, but it will still maintain the same shape and dimensions. If any tangential force, say two grams per sq. cm., is arbitrarily assumed as the starting point, then one bounding ordinate may be erected thru this point, the other being three minutes later. The position of the first ordinate will depend upon the consistency of the paste, but the average value of the tangential force between the two ordinates (which is the plasticity figure) is independent of consistency. This plasticity figure ranges from about 5 for the most plastic limes to 20 for the least plastic.

An attempt has been made to use this machine to measure the plasticity of clays, but without satisfactory results. This was due to the mechanical design of the machine, and not to any unsoundness in its basic principle. The ratio of tangential to vertical forces is so much greater for most clays than for limes, that it was found very difficult to select a consistency such that both forces could be measured at the same time — one or the other would usually run off the scale of the machine. The force required was frequently so great that the belt driving the machine would slip. Since the results are all predicated upon a constant speed of the machine, any slipping of the belt would make them worthless.

The present machine has been used by three operators during two months, and has proven very satisfactory in measuring the plasticities of lime mortars. It is now being re-designed to give it a little better mechanical construction, but no important changes will be made. It is proposed to drive the machine by gears rather than by belt, and, by a slight modification of the lever system, to increase its working range. With these changes, it is believed that the machine will give satisfactory

readings with clays. Figure 1 shows the machine in its present development.

DISCUSSION

Mr. Riddle: I want to apologize, both to the members and also to Mr. Emley for any incorrect abstracting of this paper. If it were my own, I might be able to cut some of the less important things out and tell you the important ones. To start with, the machine was built for the testing of different kinds of wall plaster, and later it was tried out for clays under similar conditions. In the case of the wall plaster we used two kinds of disks, one of them is plaster of Paris boiled in paraffine to make it a non-absorbent base, and the other is simply regular plaster of Paris which is absorbent. In the case of clays, only the non-absorbent one would be used, so in this article, we will only read about that one and neglect the other entirely.

Mr. Denmead: I would like to know how the clay sample is made; in other words, what form of clay, etc., is used in testing the clay.

Mr. Riddle: We have this disk which I spoke of, and the clay sample is put on top, there, by means of this rubber mold. It is simply pressed into the mold, and then the piece taken off leaving the clay disk in position, and then the whole thing is put under the trowel that way and lowered, of course, so that it will be in the right position. The clay would be in between and as this rises, the clay is pressed against the trowel. As the pressure increases, it will naturally spread, and that spreading of course will be measured on this lever, while the friction will be measured with the other lever.

Mr. Denmead: Is the rise there driven from a motor or done by hand?

Mr. Riddle: The rise is driven, the other is not, it is just one that is driven; this one simply rises by friction.

Mr. Shaw: Do I understand the principle, that it is the measurement of the friction between that disk and the clay? Is that the principle involved there?

Mr. Riddle: Yes, sir, that this is the way I understand it.

Mr. Shaw: Then if you made that disk of glass instead of the material of which it is made there, it would give you a different result, would it not?

Mr. Riddle: Yes, sir.

Mr. Shaw: Then the measurement of plasticity with that machine means a relative plasticity, referred always to the material that you are using as the trowel of the machine.

Mr. Riddle: What do you mean by glass? Fine ground glass or a solid chunk of glass?

Mr. Shaw: I mean a friction disk made of glass instead of the material of which that is made.

Mr. Riddle: It would not matter what this was.

Mr. Shaw: I mean the one representing the trowel.

Mr. Riddle: Well, I would say that that should always be the same metal. That is just my own idea of it, though. If you were to use glass, you might have some different friction from what you would have using a trowel. I remember that Mr. Emley said that, under some conditions, for instance if you were to press a very non-plastic substance hard enough, you would probably press the water to the surface and create a false absence of friction there which might be erroneous, but I am not able to state that definitely.

Mr. Stover: I would like to state that if this is just a new machine, that it would be of much more use to the potter if, before this goes into the Transactions, a series of tests of ball clays and kaolins as regards their relative plasticity with the different amounts of ground stuff added, would add greatly to the value of the machine, and, that I presume, we will find in the Transactions.

THE FINE GRINDING OF REFRACTORY MATERIALS BEFORE TESTING

DISCUSSION

Mr. R. J. Montgomery: In testing fire-clay refractories one of the most important problems that has to be solved is the determination of the quality of brick that should be used in a position where a given temperature is reached, allowing a certain margin for abuse during operation. The usual tests made are the load test, the fusion test and a reheating test in some form to observe the temperature at which excessive shrinkage or overfire begins. It is very hard to draw definite conclusions from these results, as it is known that the short laboratory burn is not as severe as long service in operation. A certain relation must be established between tests and service by trial, but when the installations are expected to last from two to ten years, trial is not very feasible.

It is customary for manufacturers to exaggerate the temperature that the various refractories will stand, for instance, from 3200° to 4000° F. is claimed for silica brick when it actually will melt at not over 2960° F. There is also a tendency to adopt methods of testing that will make a brick stand as high a temperature as possible, that is by testing the brick made of coarse ground material as received. I believe that often false interpretations of results are made because the time factor is not sufficiently considered. The temperature of softening or of failure under load is based, not upon the true chemical composition of the brick, but upon a combination of composition and structure which gives abnormally good results. It is unquestionably correct to use coarse material in brick manufacture to give an added factor of safety, but in testing I believe this factor should be eliminated as far as possible.

I have taken a mixture of silica and clay corresponding to the silica-alumina eutectic in composition and have varied the softening point from cone 31 to cone 26½ by increasing the

fineness of the grind. In use, extending over a long period, I believe this mixture would slowly sinter and finally soften at cone 26½ regardless of the original coarseness.

Why shouldn't we, as nearly as possible, determine the minimum refractoriness instead of the maximum? By grinding the samples of brick and clay finely before testing, we may to a great extent disregard the time factor and obtain results based more nearly upon the actual chemical composition which after all is the really important thing.

Our furnaces, ovens, etc., should not be built of material which owes its lasting qualities to a gamble on whether sintering will progress far enough to cause ultimate fusion. The material should be chemically able to withstand operating temperatures.

I regret that I cannot submit data to back up the point raised, but I feel it is important and should be seriously considered by the committees at present working on Standard Specifications for Refractory Materials. Just what tests should be made on fine ground materials and how they should be made can only be determined by experiment.

Mr. Montgomery: The subject as announced on the program is not quite right, because instead of a note, it is the opening of a discussion, and my part of it is very small. I want to bring up the subject and that is all. I had intended to bring a number of samples of refractory brick clay and silica, but they were too bulky and I could not get them over here. For instance, we have had silica brick in constant operation in coke ovens for nine years, at an operating temperature of at least 2,600° F. Now, nine years service at 2,600° or above is a very severe test for a refractory, and if that refractory was not fundamentally able to stand that temperature, it would not be in use today; in fact, the brick is in as good a condition as then, and the cement used is still in place in very good condition. We have a tendency to use fire-clay brick beyond their ability to stand load or to stand the operating temperature. We make a load test, and we base our conclusions on a short-time test on coarse material. In many cases we get false ideas of quality, as our tests tend to give the maximum temperature instead of the minimum, that a refractory will stand.

Mr. Purdy: Did I understand Mr. Montgomery to say that the chemical analysis after all, is the most important factor for fire clays?

Mr. Montgomery: I think the chemical analysis, when we have learned to use it, will be the most important thing in fire clays and in all refractories.

Mr. Shaw: One point Mr. Montgomery raised that I am inclined to doubt, and that is, that if we grind the material fine, it will come in a short time to the condition that will be reached by fluxing of the coarser materials in a longer time. I think there is considerable doubt whether that is true or not. In a fine ground condition, we bring the brick to a uniform mixed condition, and you have, in intimate contact, the materials which will form the eutectic mixtures and which will cause the failure of the brick. In case of the fusion over a longer period of time, there is not the opportunity for the formation of those eutectic mixtures, because the materials are not in condition to be sufficiently mixed to bring them into intimate contact, and therefore the prime factor in that case is the very thing that does the work; the short-time test would not do, and I do not believe the intimate grinding of the material would produce the same effect as the longer time test does.

Mr. Staley: It seems to me that the relation of fineness of grinding to the fusing point of clays is perfectly capable of demonstration by laboratory experiment. I assume that Mr. Montgomery will be very glad to do the necessary work. If he does not care to do it, I will undertake to carry on the experimental work connected with this question. We can do it readily in our laboratory, and I think it is worth while investigating. I would like to have a statement from Mr. Montgomery whether he'd rather do it or turn the proposition over to us.

DISCUSSION SUBMITTED AFTER READING PAPER

Mr. Ries: While I agree with Mr. Montgomery that it may be desirable as a matter of safety to determine the minimum instead of the maximum refractoriness, at the same time I cannot bring myself to believe that it is a wise procedure to grind up a brick before testing.

Some 15 years ago in my report on the New Jersey fire clays, published in Volume VI of the New Jersey Geological Survey, I published a number of fusion tests of fire brick in their natural texture and in ground condition. There it was shown that in every case the fusion point of the brick after being ground to 100 mesh and remolded to cones, was appreciably lower than that of the brick in its natural condition.

Until we have more definite data I do not consider it safe or wise to say that the time factor will completely offset that of texture.

HUMIDITY, ITS CONTROL AND RELATION TO THE DRYING OF CLAY WARES.

BY W. A. DENMEAD

Sometime ago our factory was confronted with the necessity of speeding up deliveries, and it was evident that the rate of drying was the limiting factor. The writer having been with Mr. E. D. Gates soon after his rough experiments on drying with controlled humidity, (reported in the Transactions of this Society) became greatly interested in the problem, having always felt that although the results were not wholly satisfactory, they were sufficiently promising to ensure success under somewhat better control and understanding of the requirements. We have been continually experimenting with considerable success during the past few years as to the effect of humidity on the drying behavior of electrical porcelain, and our investigations have brought to light some interesting features of control, fundamental principles, etc., which it was thought might be of interest to the Society.

We have found that wonderful results can be achieved where conditions are just right and, therefore, the success of drying with artificially moistened air depends entirely upon an understanding of drying phenomena and the efficiency of the automatic control apparatus. Our experience does not warrant the writer in stating just how successful the control devices are, but testimonials from textile mills and many other plants, where very close control has been found almost a necessity, would indicate that the apparatus is very satisfactory.

The writer is indebted to the G. M. Parks Company, The Carrier Engineering Corporation and The Philadelphia Textile Machinery Company for much aid in supplying data, cuts, etc. It has been found impractical to explain in this paper the workings of the apparatus shown in the cuts except in a most general way, but further details can be obtained on application to the manufacturers. The writer has been fortunate in seeing much

of this apparatus in operation and has picked these cuts to give some idea of unique features, simplicity, nicety of regulation, etc., and is satisfied that apparatus suitable for one class of work is not necessarily the best for another. The wide variety shown, though only a small part of that available, is merely to call to your attention a few schemes of controlling the rate of drying. The lack of attention to this, I believe is responsible for enor-

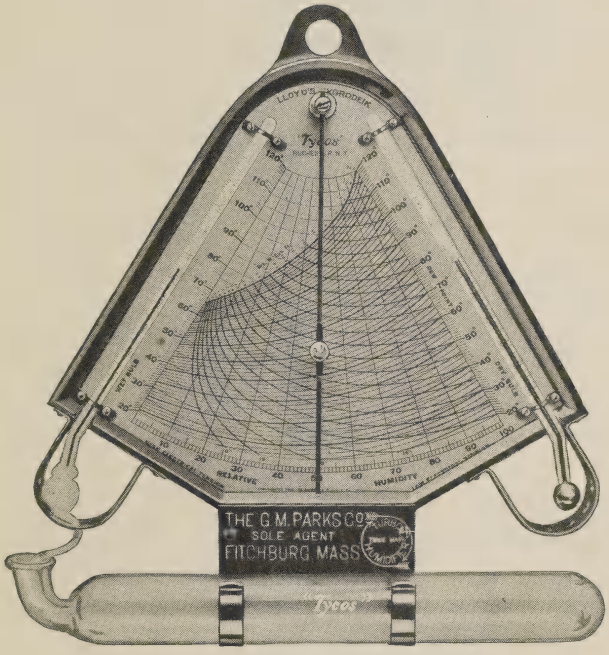


FIG. I. Hygrodeik.

mous loss of time and ware, as well as unbalanced operation or failure to obtain maximum output with given facilities in other departments.

It is a little difficult to present this subject to a mixed body of technical and practical men and those who are the happy combination of both, but if the technical men will pardon me a moment I will explain a few details necessary for the proper understanding of relative humidity control. The term "relative

humidity" may be defined as the ratio between the moisture content of the air and the greatest possible content at the same temperature, multiplied by 100. For instance, air at 70°F. can support as vapor 7.9 grains of moisture per cu. ft., and if the air at a stated time does contain 5.1 grains per cu. ft. then the relative humidity is 5.1 divided by 7.9 x 100, or approximately 64. Air at different temperatures can support widely different amounts of moisture, and at 90°F. may contain a maximum of 14.7 grains per cu. ft. while air at 60°F. can only contain 5.7 grains per cu. ft., and if more moisture is present dew will result. Table I gives a few figures showing the moisture-carrying capacity of air at several temperatures, also the moisture content at several relative humidities for a temperature of 70°F.

TABLE I

TEMPERATURE DEGREES F.	GRAINS OF MOISTURE PER CU. FT. SATURATED AIR.	PERCENT RELATIVE HUMIDITY AT 70 DEG. F.	GRAINS OF MOISTURE PER CU. FT.
60	5.7	25	1.9
70	7.9	50	4.0
80	10.9	75	5.9
90	14.7	85	6.7
100	19.7	100	7.9

The higher the relative humidity of the air (or nearer to saturation), the slower it will be to take up moisture and therefore the slower the drying of the ware with which it is in contact. The simplest instrument giving relative humidity readings, is the Lloyd's Hygrodeik, shown in Fig. 1. This instrument depends on the difference in temperature of two theromometer bulbs, one kept moist while the other is dry. The moist bulb, owing to the cooling action of evaporation, is colder than the dry bulb, except in completely saturated air, the extent of this temperature difference being proportional to the rate of evaporation on the surface of the wet bulb. This evaporation is governed by the vapor tension which in turn is controlled by the amount of moisture in the atmosphere compared to the maximum possible content, in other words relative humidity, the desired readings

are obtained by means of a simple chart. This instrument is not exact but serves fairly well for comparisons, or to obtain a rough idea of the drying conditions at any desired point.

I dare say that practically all of you have tried various stunts to prevent or slow-down drying, such as covering with

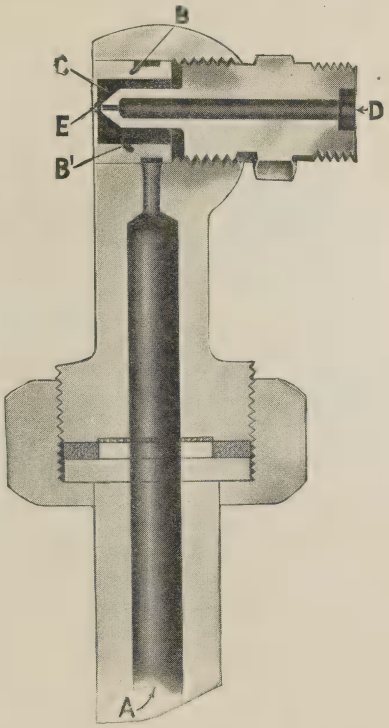


FIG. 2. The Turbo principles are: Air applied tangentially, the injector idea and centrifugal force, all in this small but efficient instrument.

wet bags, piling close together, placing in a part of room free from drafts, or colder than the balance, in canvas-walled compartments, etc., and have attempted to hasten drying by building paper fires inside of parts, using an incandescent lamp or one of many means of applying heat locally. Just what were you doing? Simply changing the relative humidity of the envelope of air immediately surrounding the piece. Thus by placing ware

in a canvas-walled compartment you stop air circulation to a great extent with a consequent rise in relative humidity of the air immediately in contact with the ware due to evaporation in a restricted space, thus slowing the drying. In another instance, by placing an incandescent lamp inside a bushing near the bottom, you are creating a circulation of air, also raising the temperature (permitting the moisture carrying capacity of the air to be increased), thus reducing the relative humidity and hastening the

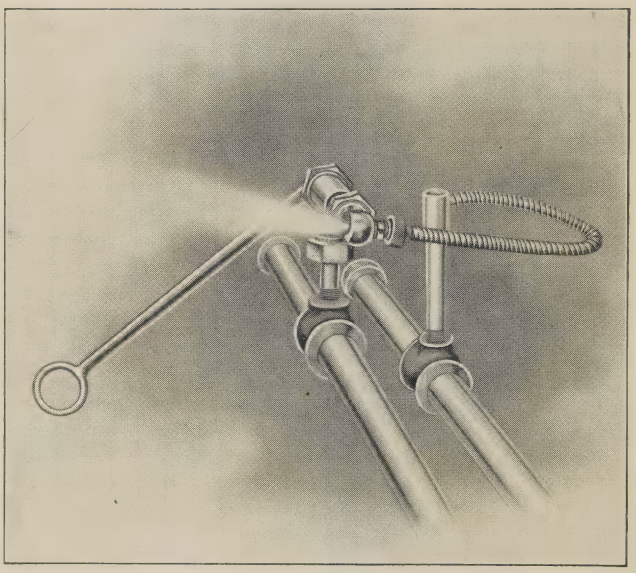


FIG. 3. In the Turbo system the water is not under pressure — No damage possible from overflowing water.

drying of the inside of the bushing to keep pace with the natural drying of the outside.

Drying depends on capillary action and difference in vapor pressure, but this latter is directly controlled by the relative humidity of the air envelope and is by far the greater factor. The raising of the drying temperature tends to reduce the relative humidity of the surrounding air which in turn reduces the vapor tension causing an increase in the rate of evaporation. From the above, one's first thought is "Why do all this juggling

of ware with covers, local heat, etc., and why not control the atmosphere and temperature of the room and dry as rapidly as experience finds safe?" It is the opinion of the writer that this is the solution of many such problems where losses from drying difficulties (either direct or indirect, and I believe the indirect, greatest), are sufficient to more than pay an attractive interest on such control system. I am also convinced that by the installation of such a system, designs and processes, wholly impractical under ordinary conditions, can be safely undertaken.

Probably the average clay worker fails to realize fully the great difference in summer and winter drying conditions, or, more exactly, the difference between the drying conditions at the time when windows and doors are open, with no general heating of buildings, and when windows, doors, etc., are closed and steam turned on for heating purposes. For instance, we have recorded a humidity as low as 14 in January on our greenware floor, while the average summer humidity in our section is about 72, and it is a dry day when it falls as low as 35. It is also worthy of note that when the humidity does fall as low as 40 in summer it is readily felt and steps may be taken to protect delicate ware. Thus it will be seen that drying is taking place several times more rapidy in winter than in summer, with the result that as soon as the heat is turned on in the fall and windows closed the drying losses, as well as kiln losses, are very likely to increase to an alarming extent unless vigorous action is taken to protect the parts from such rapid drying. It seems unnecessary to state that such losses could be immediately eliminated by artificial humidification to the necessary relative humidity. The proper relative humidity can only be determined by experiment, as it will undoubtedly vary for different wares. There are of course certain plants where such installations could not be profitably made, but from the writer's experience it would seem that the only plants where great objection would arise would be where plaster molds and ware are dried in the open without application of additional heat, in which case the drying of molds will be retarded when the ware is dried more slowly. It is worth mentioning, however, that in no case would the results be worse than those of summer, providing the relative humidity is not raised above that encountered during the summer.

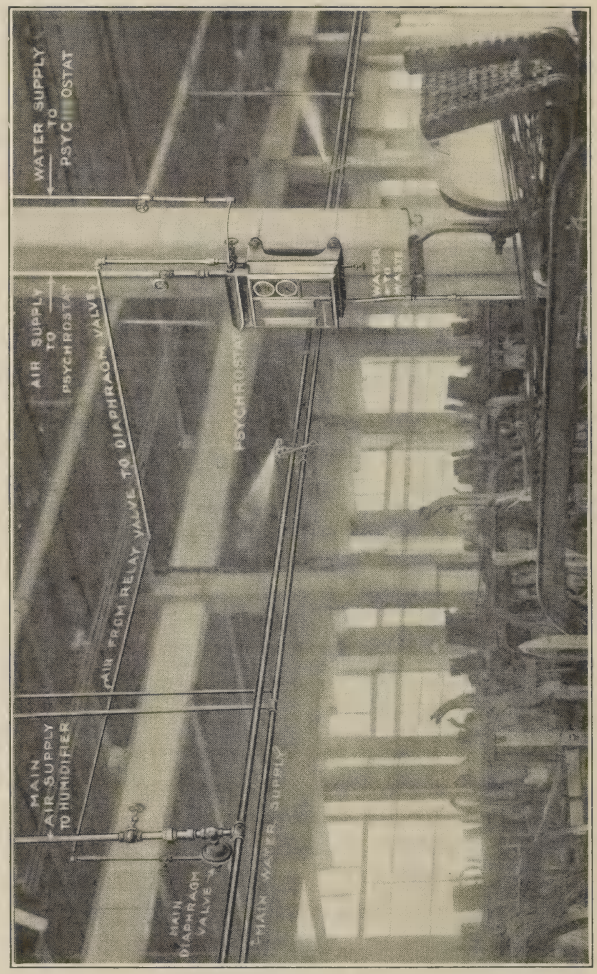


FIG. 4. The Psychostat actually at work in a weave room as a commercially practicable instrument.

The writer believes that in general two distinct periods should be recognized in the drying of clay ware, and that in many instances best results can only be obtained by recognizing such stages and arranging controls accordingly. The first period covers the drying from the forming of the piece, by whatever means employed, to the leather-hard or handling stage, and the second period, from that state to the final dried condition. The first period is the one most often neglected, and experiments indicate that almost as much damage may be done in this stage as any other, for though no cracks may result, our investigations indicate that a piece carefully controlled in this stage can be dried from the leather-hard state to finish much more rapidly or under more severe conditions than a piece to which no attention has been paid in the first stage. It is a well-known fact for instance, that many bodies and clays shrink very little after the leather-hard stage (our own clay averages about 2 percent), and therefore the most severe strains are set up long before many clay workers feel care need be exercised, or in general before the ware ever reaches the drier. It is thought that control of the rate of drying in this first stage would result in greatly reduced losses at many plants. The control would be very simple, being merely a matter of regulating the humidity of the pressing or forming rooms. For humidifying the press room it would seem that an over-head atomizing system under automatic control, such as is used in many spinning mills, would be most satisfactory.

Figures 2 to 8 show various parts of apparatus supplied by one concern for spinning mill humidification and which the writer thinks is readily adaptable to first-class control. This system depends upon the automatic control of the air supplied to the atomizers, and is so arranged that the air is passing thru the spray heads (See Figures 2 and 3), creates a vacuum at the nozzle which is sufficient to raise the water from the level of the lower pipe shown in Figure 3. This arrangement overcomes any possibility of overflow of water when atomizers are either on or off. The water is maintained at a constant level by tank and float valve. The atomizer is very simple, and with proper water and air filters on main lines is not at all likely to clog. No harm, except the shutting down of the individual atomizer is done if it

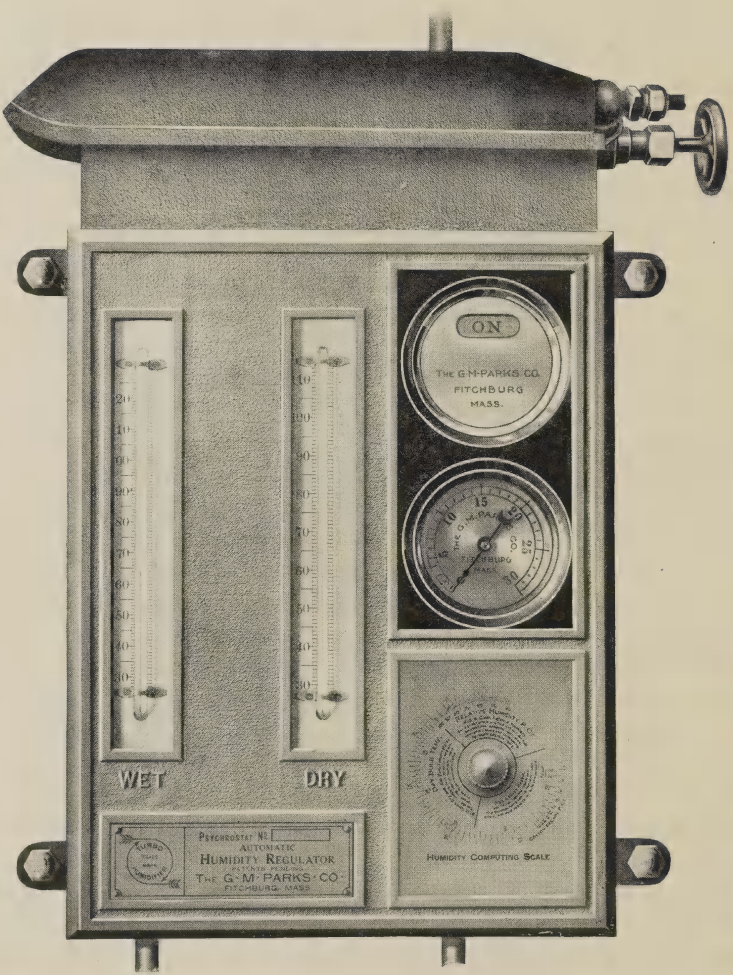


FIG. 5. Wet and dry bulb thermometers; lower gage indicates air pressure on system; upper gage indicates whether humidifiers are on or off; patented humidity computing scale is shown in lower right hand corner.

does clog, and the head is easily dismounted for cleaning. A further advantage is that each head is under individual control (note adjusting lever, Fig. 3), which permits of controlling the conditions in any part of the room at will. The atomizers are adjustable for a wide range of water delivery. The automatic control device is very simple, and its working may readily be followed by an examination of Figures 4 to 7, Figure 4 showing the complete system and Figures 6 and 7 the operation of the various parts of the control device in detail. Figure 7, sketch A, shows the wet member expanding, which means that the humidity is too high; therefore all parts of the apparatus are shown in position that permits of no air passing to the atomizer heads. Sketch B shows the reverse, when the wet member is contracting and parts are set so that air is passing to the atomizers, the humidity of the room being too low. It is only necessary to understand that the expansion tubes (wet and dry members), are rigidly fastened at the base (see Figure 6), and that parts connected to the operating lever are attached to the upper ends of the expansion tubes to properly understand the operation of the device. Adjustments for desired humidities are made by turning the nut at the top of the dry member which lengthens or shortens this member as desired. The writer has seen this apparatus working, completely covered with dirt and lint, which would indicate that it is adaptable to any ordinary plant conditions.

Figure 8 shows a small cluster tank which can be used in experimental installations, thus avoiding much expensive apparatus required in general humidification. This tank can of course be connected to the psychrostat (not shown), the same as the large mill installation shown in Fig. 4. Further details of the operation of this system can be obtained by application to the G. M. Parks Company, Fitchburg, Mass.

Upon several occasions, engineers have reported such high humidities in their localities that drying is often at a practical standstill for considerable periods during the summer. We do not experience such conditions in our locality and therefore have never had any experience with methods of overcoming the difficulty, but since hearing of the above fact I have looked into

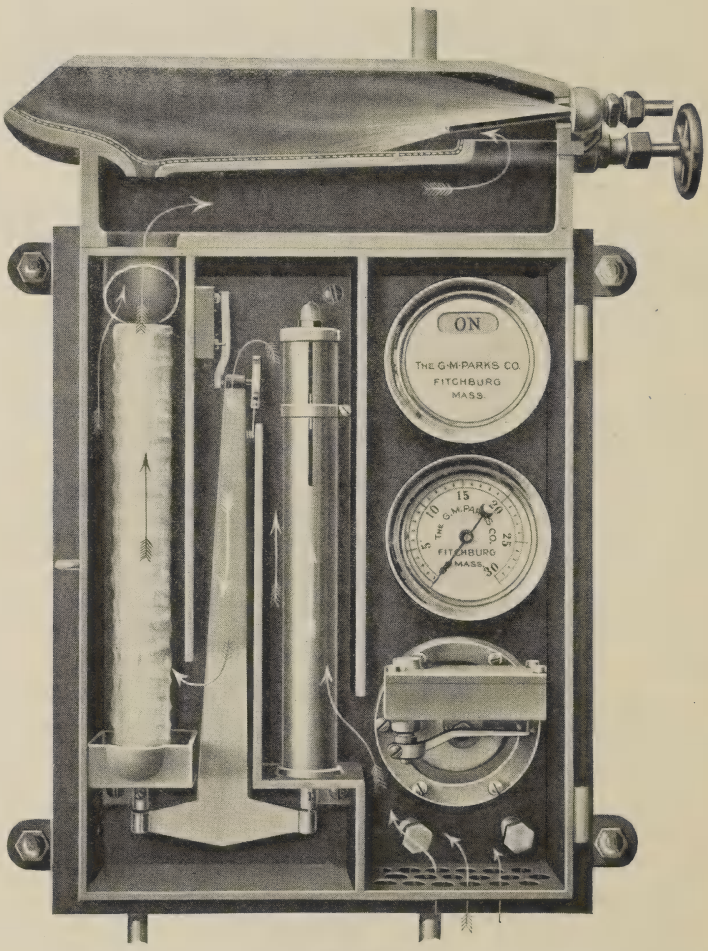


FIG. 6. The Psychrostat

the possibility of using the humidifying and cooling apparatus shown in Fig. 9 for producing normal drying conditions, and it appears that this device is a perfectly feasible proposition for limited floor areas. Where such high relative humidity conditions are encountered, humidifying with such an apparatus would be more desirable than by the system shown in Figs. 2 to 8. The operation of this cooling system should not be more expensive than the system shown in Fig. 10 except during periods when cooling of the spray water, below the available temperature, is necessary in order to reduce the relative humidity to the desired point. A hasty investigation would indicate that during the time when drying is at a standstill, the expense would be justified, especially where rapid deliveries or continuous operation of all departments are necessary for general economy.

The second period covers the drying at temperatures in most cases far above that of the forming rooms, though the variety of ware and means of drying vary so greatly in the production of different clay products, it is difficult to define this period as accurately as the first. In the majority of plants, the ware is put over steam coils, in drying closets, thru tunnel driers, on hot floors, or some other means is used to hasten the drying. Here again artificially controlled humidity could be successfully applied in many plants, or better yet a compact drier similar to one shown later could be installed to greatly facilitate delivery, which when properly regulated to your ware should cut down both drying loss and time. It is quite possible that with the use of a drier of this kind some types of ware could be dried from start to finish without separate first-stage drying. This would of course apply only to ware that could be put into drier immediately after forming.

Let us digress a moment here to show what is taking place in two ordinary driers, considered from a temperature-humidity stand point. First, suppose we take the tunnel drier, which with variations, involves the entrance of the wet product at a low temperature which is gradually raised as the cars advance. Almost immediately after entering the drier the ware is in an atmosphere of high humidity, the heat is gradually increased but long before maximum temperature is reached the relative

humidity begins to drop, otherwise dew would be deposited on the colder entering ware. After reaching a maximum temperature the drying takes place very rapidly, the humidity being automatically reduced as the car advances. This scheme is amply

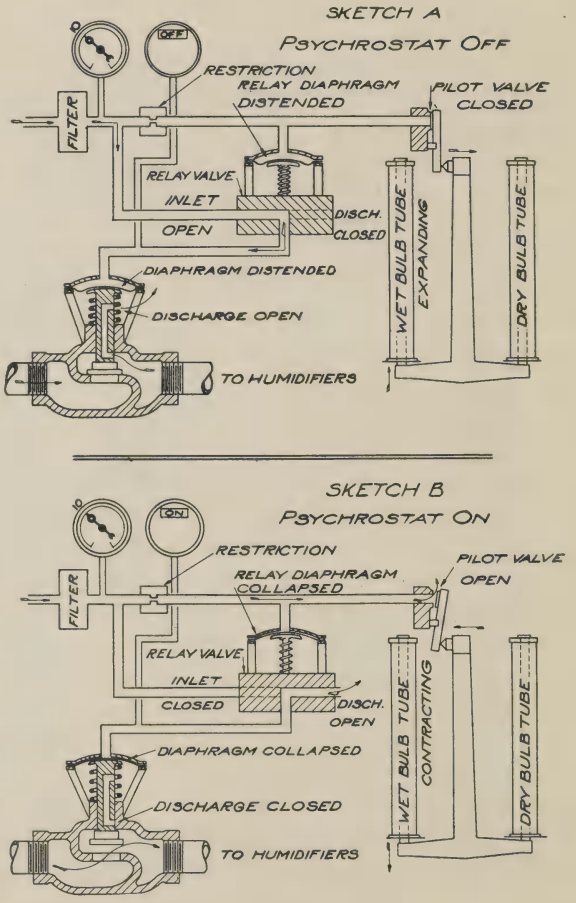


FIG. 7.

safe for much ware but at best is only a rough approximation of the desired conditions, namely, heating to the highest temperature in a nearly saturated atmosphere, then gradually reducing the humidity as rapidly as safe drying of the ware will permit.

The closet drier, on the other hand, reaches a high humidity usually a number of hours after the steam is turned on and though still safe for a type of ware, such as china, would result in high loss of even very simple shapes of wet process electrical porcelain. This is the case because the relative humidity is not high enough to prevent rapid drying the first few hours, which though not materially injuring a china plate, because the plate is so thin that drying takes place fairly uniformly throughout, would not do at all for heavy, dense ware owing to the strains set up by non-uniform drying.

The conditions of the above driers can be improved, where ware is now giving trouble, or where time of drying is an important factor simply by arranging a humidifying device with automatic temperature and humidity control, such as some of the units shown in the following cuts by means of which daily or hourly changes of temperature or humidity, or both, can be effected in a similar manner and with the same ease as the well-known temperature regulators in use in so many buildings today. It would of course seem that, where the character of the ware would permit, some modification of the tunnel drier, such as shown in Fig. 20 would be the ideal condition, but it is recognized that some wares would not lend themselves to such handling.

Figure 10 shows a general view of a complete mechanism for air conditioning, together with various control units, Figs. 11 and 12 showing interior views to give some idea of the spray chamber and water eliminators, the latter being necessary to prevent free water being carried over with the air. Complete details are too lengthy for presentation here and can be obtained on application to The Carrier Engineering Corporation, New York City. In brief, however, air passing thru this apparatus is completely saturated and the relative humidity of the air entering the room to be humidified is determined by the temperature of the air coming from the washer. For illustration, if 60 percent relative humidity at 80 deg. F. is required for the room, then each cu. ft. of air must contain 6.5 grains of moisture. If the saturated air coming from the washer is held at 64 deg. F. at the outlet, then 6.5 grains of moisture are contained in every cu. ft. and all that is necessary is to pass this air over heated

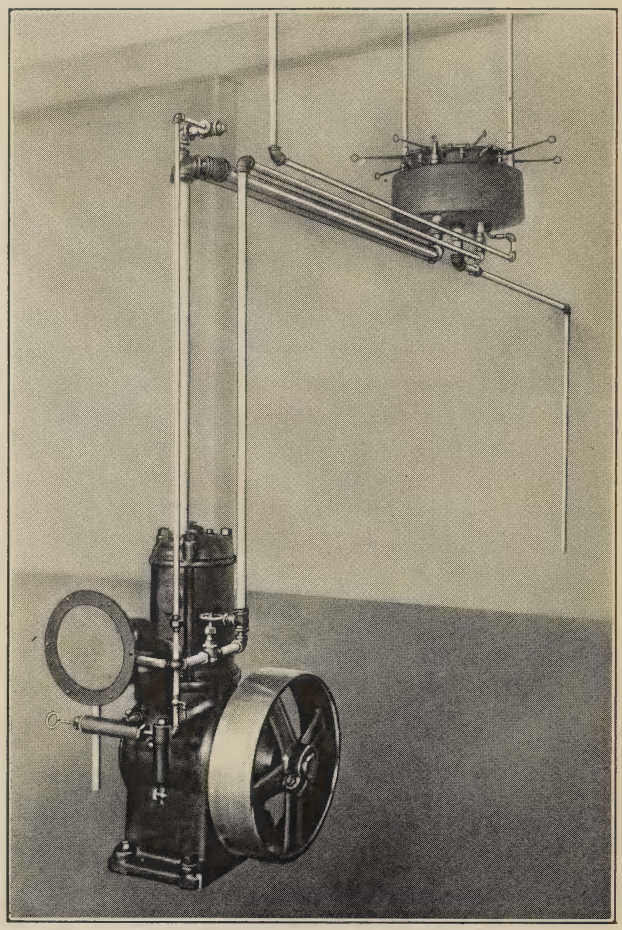


FIG. 8. Shows one arrangement of the Turbo cluster tank.

coils to raise it to 80 deg. F., the required temperature, the desired relative humidity being automatically obtained. It will be noted from this that the control of the temperature of the emerging air is the heart of this apparatus. The dew point control, Fig. 13, accomplishes this result and is a combination of expanding and non-expanding tubes, the inner tube being the non-expanding member. The relation of the regulating valve seat with reference to the non-expanding stem may be varied by the adjusting post at the front of the instrument, thus giving any desired temperature for closing. When the temperature of the air going thru the washers is too low, the valve of the dew point control is open, and compressed air passes thru the device opening the steam injector, raising the temperature of the spray water which of course raises the temperature of the air passing thru the spray chamber. When the temperature of the air passing over the dew point control is too high the control valve is closed, shutting off the compressed air which actuates the steam injector valve, cutting off the steam. This device presupposes that the water temperature is always sufficiently low to reduce the air temperature to the desired point, which is the case except where the humidity is extremely high in hot weather. Where this condition is often encountered, apparatus such as shown in Fig. 9 would be necessary if it is essential that low humidities be maintained. It will be noted that this apparatus is the same as that shown in Fig. 10 with the addition of a cooling device. In general, this addition is not necessary except in cases as outlined in the explanation of Fig. 9. The same air system which operates thru the dew point control, also operates dampers and several safety devices by means of which the apparatus shuts itself down automatically should the power, air or water be cut off. This is important to prevent possibility of very highly heated air at low relative humidity passing to the drying ware.

Figures 14 to 16 show other forms of control devices for the regulation of relative humidity regardless of temperature, while Fig. 17 shows the device for the control of both temperature and humidity. All devices of this kind depend upon a member or members, expanding or contracting at a definite rate for relative humidity changes, or on some variation of the wet

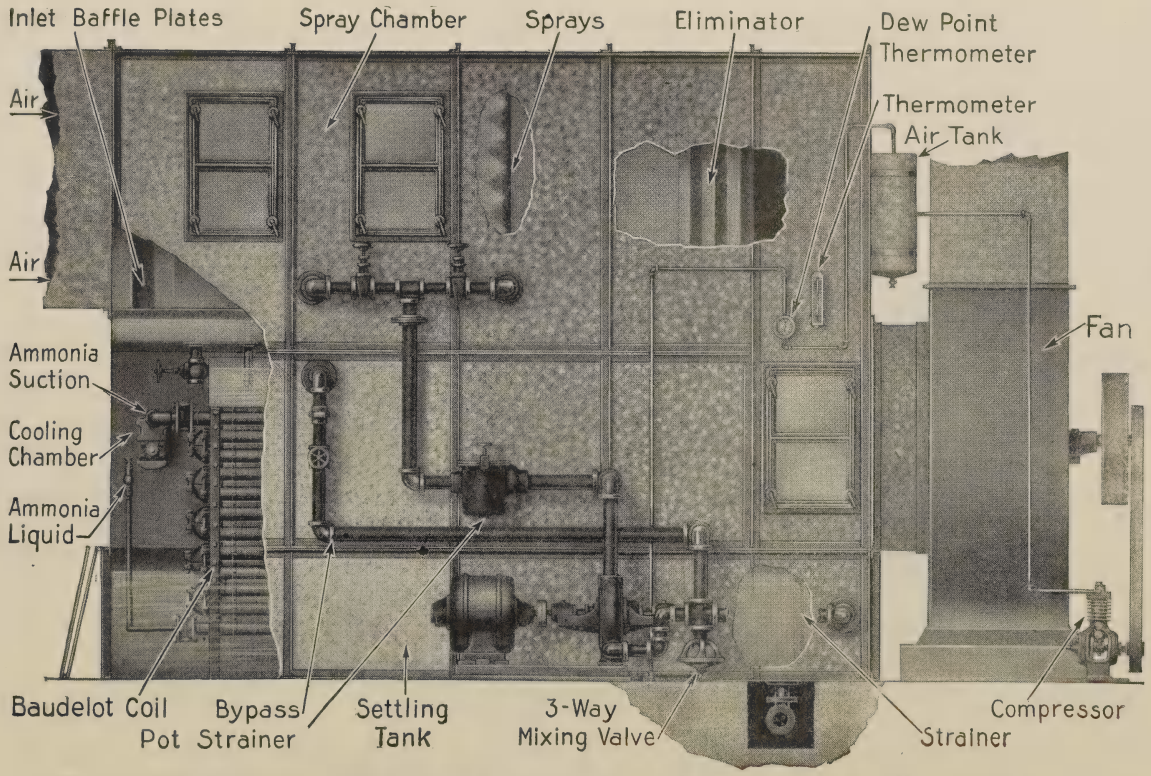


FIG. 9. Typical Carrier Dehumidifier with dew-point control and showing main parts of the controlling machine.

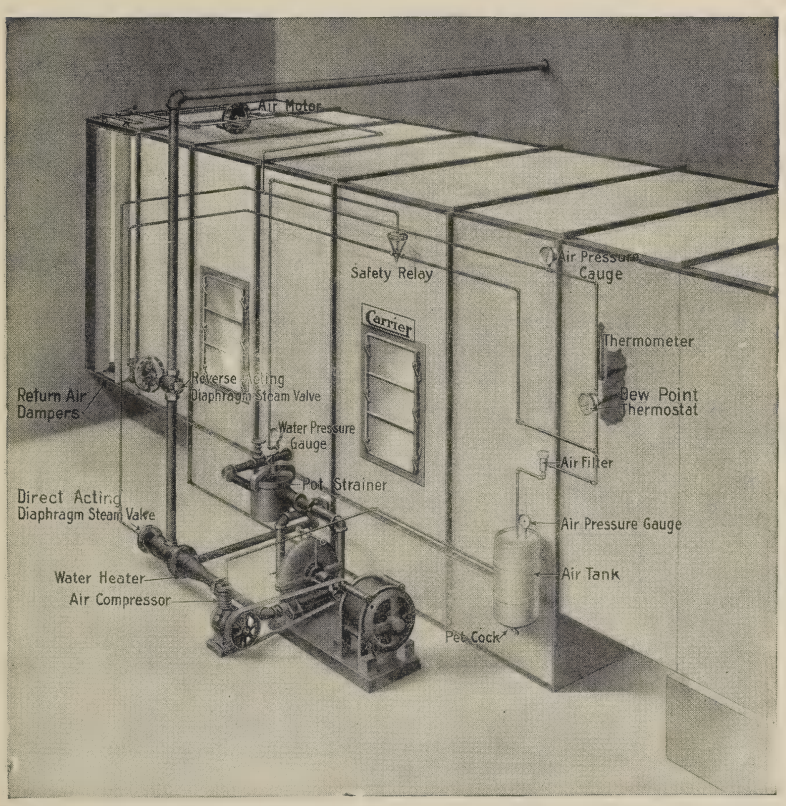


FIG. 10. Partial view of Carrier Humidifier equipped with dew-point control, and showing main parts of the controling machine.

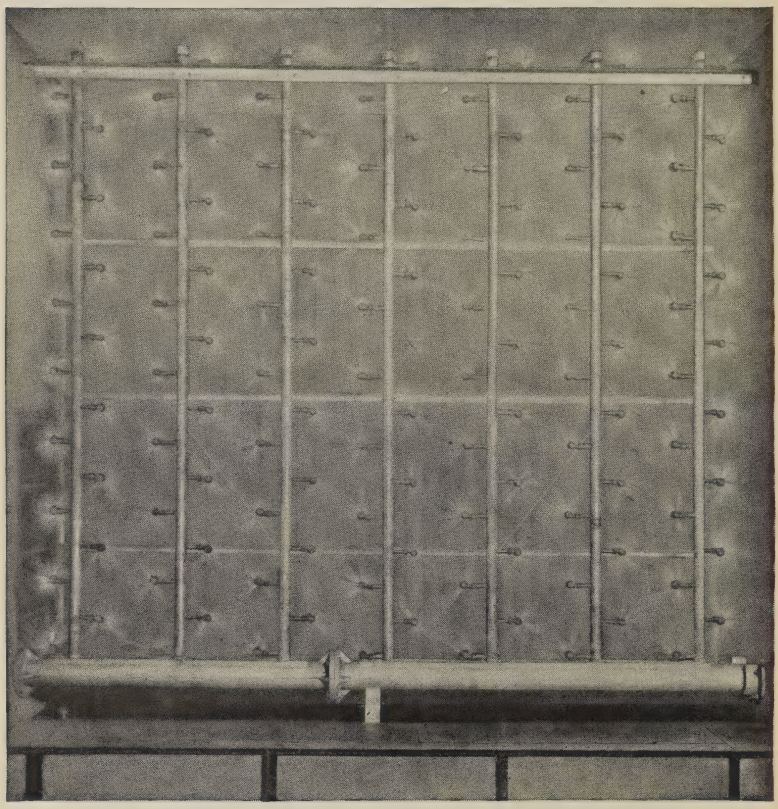


FIG. 11. Sprays in a Carrier Humidifier; note the distribution.

and dry member principle similar to that shown in Figs. 5 and 6. All such apparatus, seen by the writer, operate small compressed air relays, which actuate diaphragm valves controlling air dampers, steam, water or compressed air lines, singly or in combination. Figures 18 and 19 show charts of recording instruments demonstrating the control possible by means of these regulating devices. Figure 18 is especially interesting in that both wet and dry bulb temperature are recorded, also the wavy lines indicate how sensitive the control; each complete wave

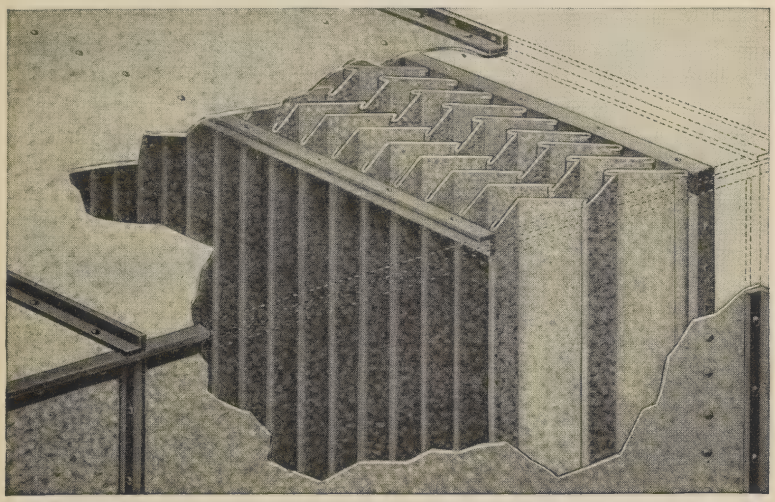


FIG. 12. Showing construction of the eliminators in the Carrier Humidifier.

indicating one readjustment of conditions from too humid to too dry back to too humid again.

Figure 20, 21 and 22 show outlines and photographs of a drier designed to enable the operator to control the various compartments by means of such devices as shown in previous cuts. This drier is of course varied to suit conditions, such as increasing the length, dividing into more compartments, varying the rate of heating or removal of moisture, etc. and appears to the writer to be adaptable to a large variety of ware. The apparatus can be designed to handle the ware on trucks which

can be brought to the workman's bench. The forming of the ware immediately on the trucks is not an impossibility and might be of great advantage in some cases. This drier has some very fine records and it is understood that 4-in. drain tile are being dried in 60 minutes at the Clay Products Company, Brazil, Ind., with conditions of control far from the best possible; indeed without the use of any automatic devices. Further details of

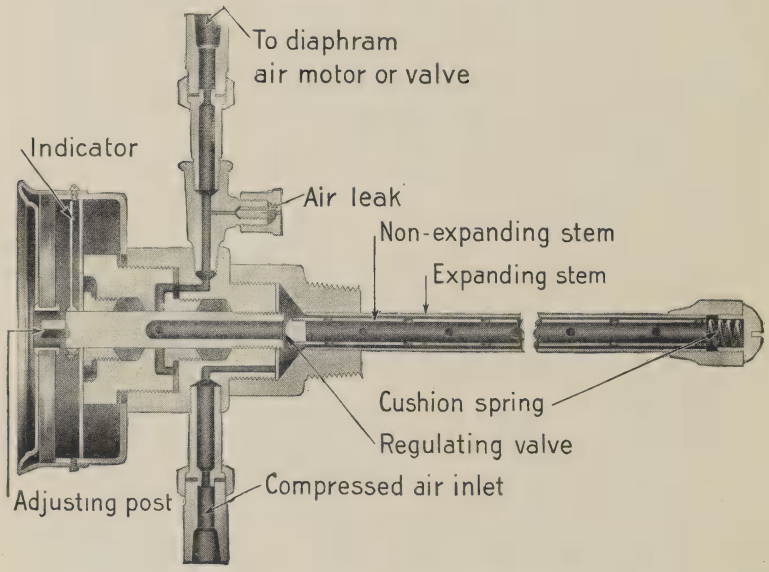


FIG. 13. Section of Carrier Dew-point Thermostat showing operating principle.

the drier can be obtained on application to the Philadelphia Textile Machinery Company, Philadelphia, Pa.

SUMMARY AND CONCLUSIONS

In our investigation of this subject the following points were brought out, or found to be worthy of thought when such control is under consideration:

1. Drying takes place more rapidly the lower the relative humidity at the same temperature.

2. Drying takes place more rapidly the higher the temperature with the same relative humidity.

3. A safe relative humidity for one ware may not be safe for another. Therefore no figures are given.

4. The relative humidity in general increases slightly from the ceiling to the floor.

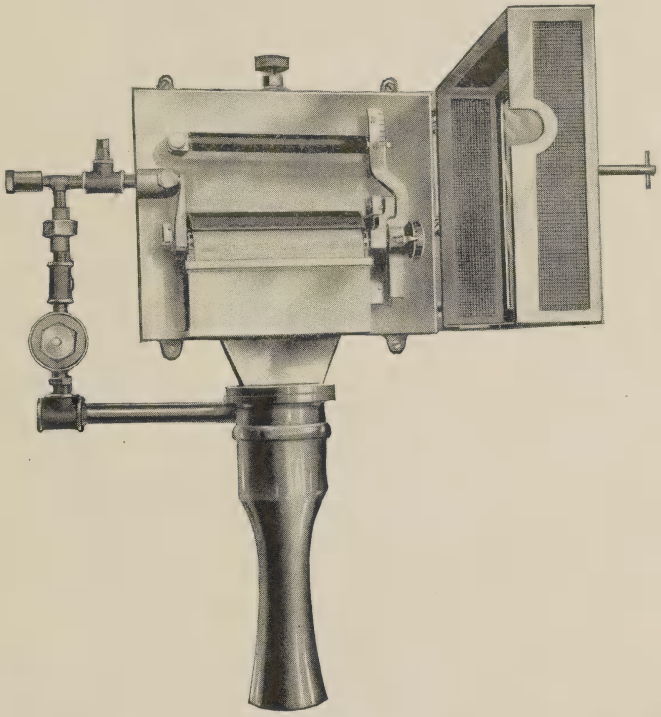


FIG. 14. The Carrier Differential Hygrostat opened to show wet and dry-bulb members.

5. Allowances must be made for escaping moisture from the buildings, which is unavoidable with any system of ventilation.

6. It is desirable to have a flexible humidifying apparatus so that ware in different parts of the room or in separate rooms can be subjected to different relative humidities. This is because many designs can be dried much more rapidly than others and

a system capable of maintaining different humidities at different spots enables one to take advantage of this fact.

7. Ware heated to a high temperature, say 150 deg. F. with a relative humidty as near as possible to 100, can be safely

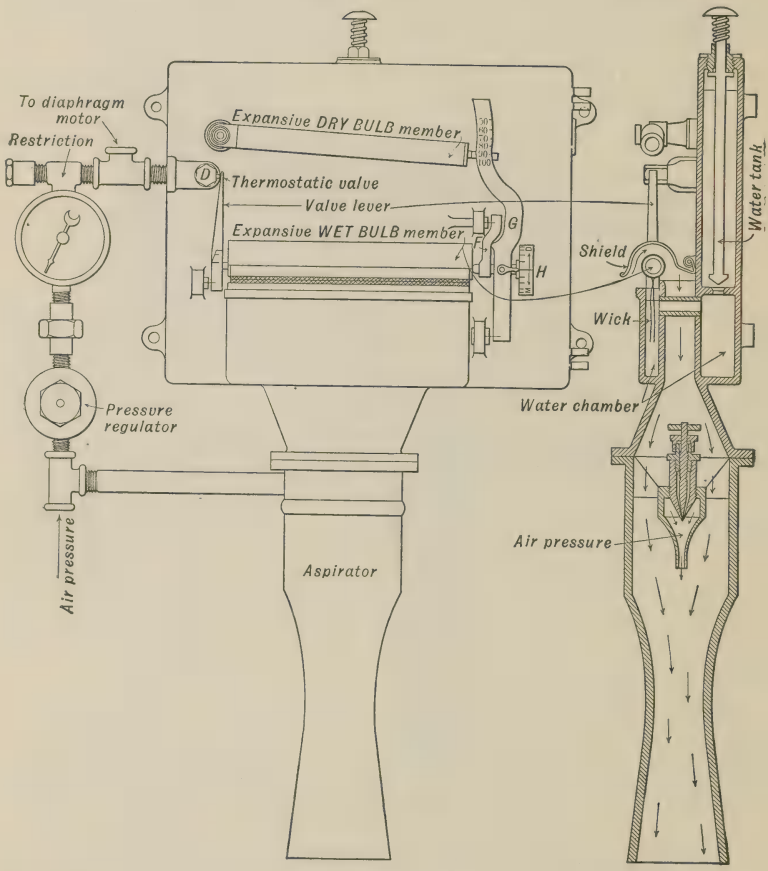


FIG. 15. Showing details and operating principle of the Carrier Differential Hygrostat.

dried much more rapidly than if it is heated to a lower temperature at the same relative humidity or to the same temperature at a lower relative humidity.

8. It is the writer's belief that any time lost in slower first-stage drying is more than compensated for by the greater possible

speed in safely drying the ware during the second stage. This has not been proven to everyone's satisfaction, but the evidence at present points this way.

9. Most ware cannot be cooled rapidly even though bone dry. The writer was amazed at finding that a drier opened at 90 — 100 deg. F. showed high loss on drawing, though the ware was apparently in first-class condition at the completion of the drying treatment. It is believed, that a failure to realize this fact is responsible for considerable loss in the drying of many products. Indeed I have seen a drier proposal where provision was made to cool the ware at a rate that would certainly result in enormous loss if applied to the ware in question.

10. In most cases it is not necessary, or desirable, to reduce the moisture content of the ware below 1½ to 2 percent as it is expensive to do so, and though it may perhaps be necessary for some very tender products with which we are not familiar, it is not necessary for most ware.

11. All leather-hard pieces examined shrink only a few percent in drying, and that shrinking takes place with the elimination of the first few percent of moisture.

12. Upon the operation of the automatic regulating devices for temperature and humidity depends the success of the system for we are convinced that if properly regulated, all systems can be adapted, though one system will undoubtedly prove best adapted to each drying problem. For the first stage in drying, temperature control is seldom essential, as the ware will usually stand variations of evaporation rate caused by any ordinary variation of workable room temperatures, provided the relative humidity is maintained within reasonable limits. If temperature control is necessary, there are a number of devices on the market for so doing.

13. The opening of windows in the shop while the humidifying system is operating will upset the regulation. This sounds like a very objectionable feature but during the period when windows can be safely opened the humidity control is usually unnecessary anyway. It is also believed that the opening of windows (creating drafts), is responsible for considerable loss under any conditions, except where very carefully attended, and

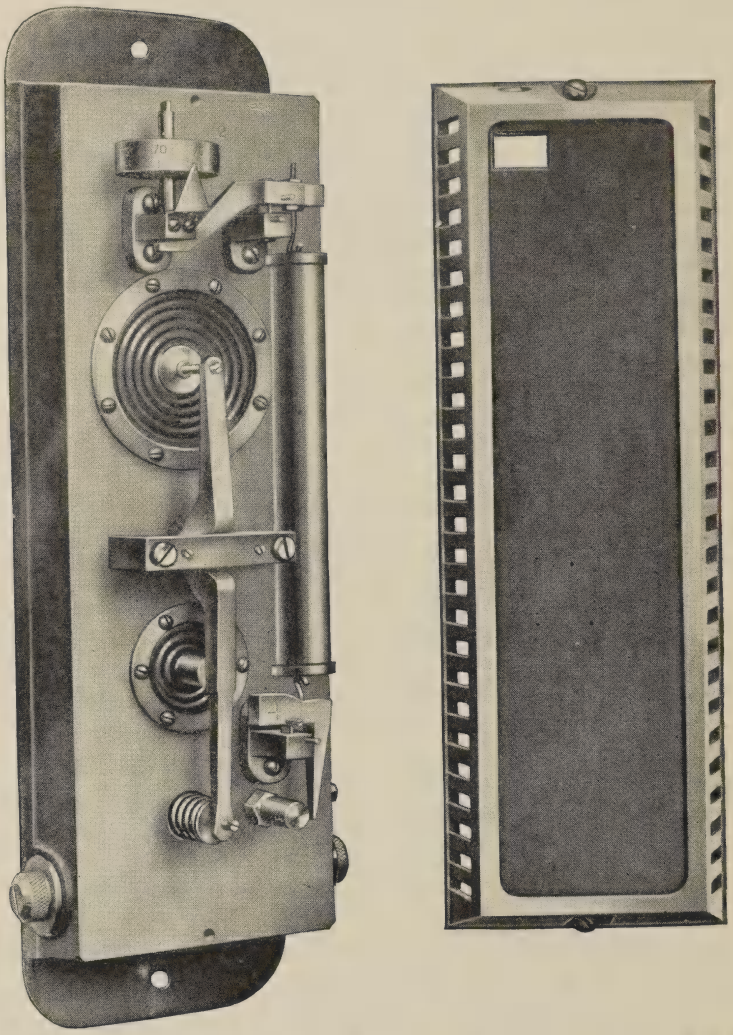


FIG. 16. The Carrier Compensating Hygrostat with cover removed to show the hygroscopic mechanism.

it is not thought that the opening of a window would result in any more serious consequences with humidity control than without.

14. Movement of air is essential in most cases, as otherwise the humidity will rise very much higher in some parts of the room or compartment than in others, depending wholly upon

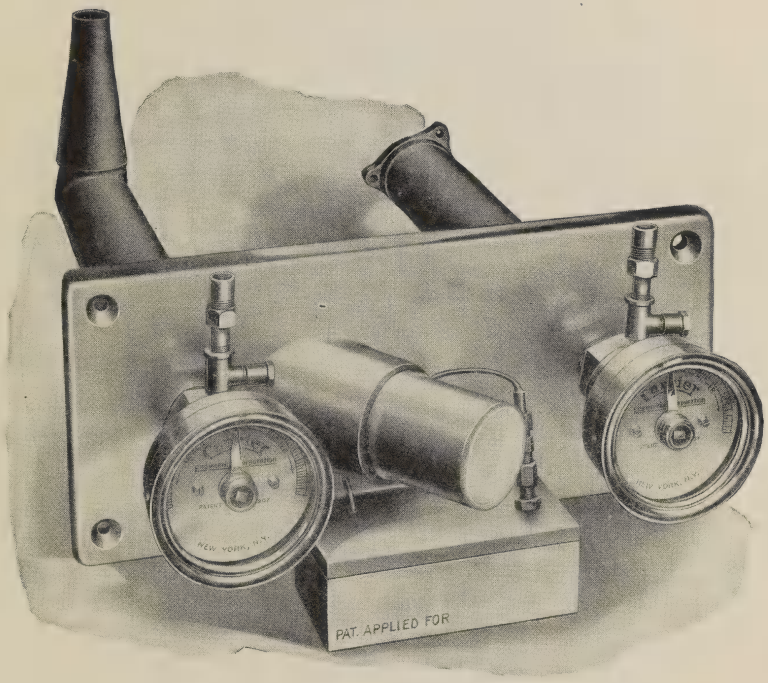


Fig. 17. Carrier Type W Regulator.

the amount of moist material and the amount of water vaporized in each locality.

15. There are certain times where a high humidity in the forming room would be objectionable, but provided the temperatures are kept reasonably low throughout the winter this should give very little trouble, and in summer when the temperatures are high it is seldom necessary to use the humidifying devices, though in some instances greater comfort can be attained for

the workers by humidifying the air as the evaporation of moisture tends to reduce the temperature. Figure 23 is a chart showing the cooling effect of water evaporated under various conditions, giving some idea of the possibilities of temperature reduction by the introduction of additional water vapor into the air.

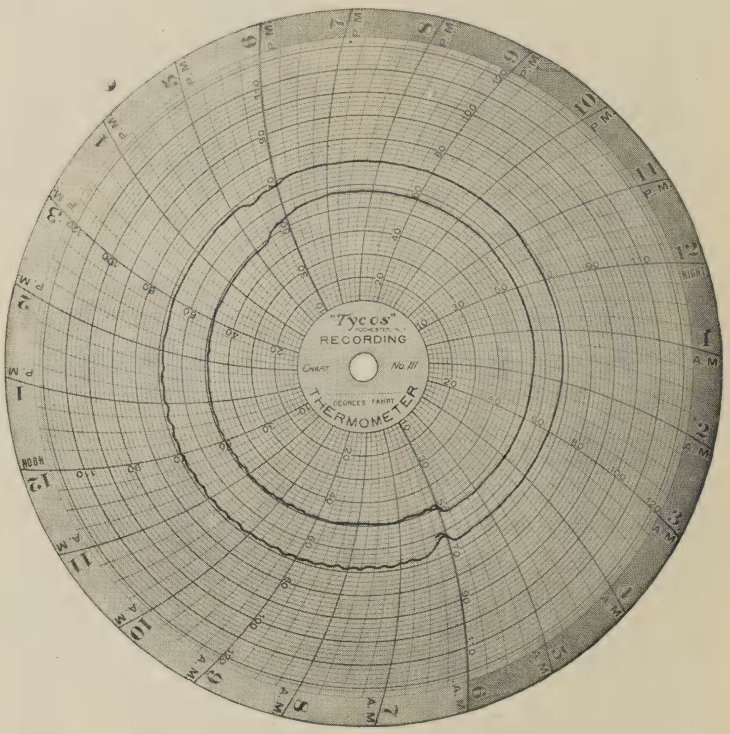


FIG. 18. Chart from the recording thermometer, showing wet and dry bulb temperatures. These charts are complete records of actual results obtained with the Carrier Automatic Dew-point Control. In this plant the regulation is desired only between 7.30 A. M. and 5.30 P. M. No attempt is made to maintain constant temperatures throughout the night. Note particularly the wavy appearance of the dry bulb temperature during the periods of regulation, this waviness indicating that the automatic dew-point control was almost continually in action, and successfully held the temperature within the 2° range for which it was set.

16. One question has arisen which has not been successfully answered to everyone's satisfaction though many possible causes have been suggested. The writer would welcome suggestions from the members as to the cause of the following:

It has been repeatedly found that ware will crack after shrinkage has ceased, and though such cracking is much less frequent when parts are carefully handled during the shrinking

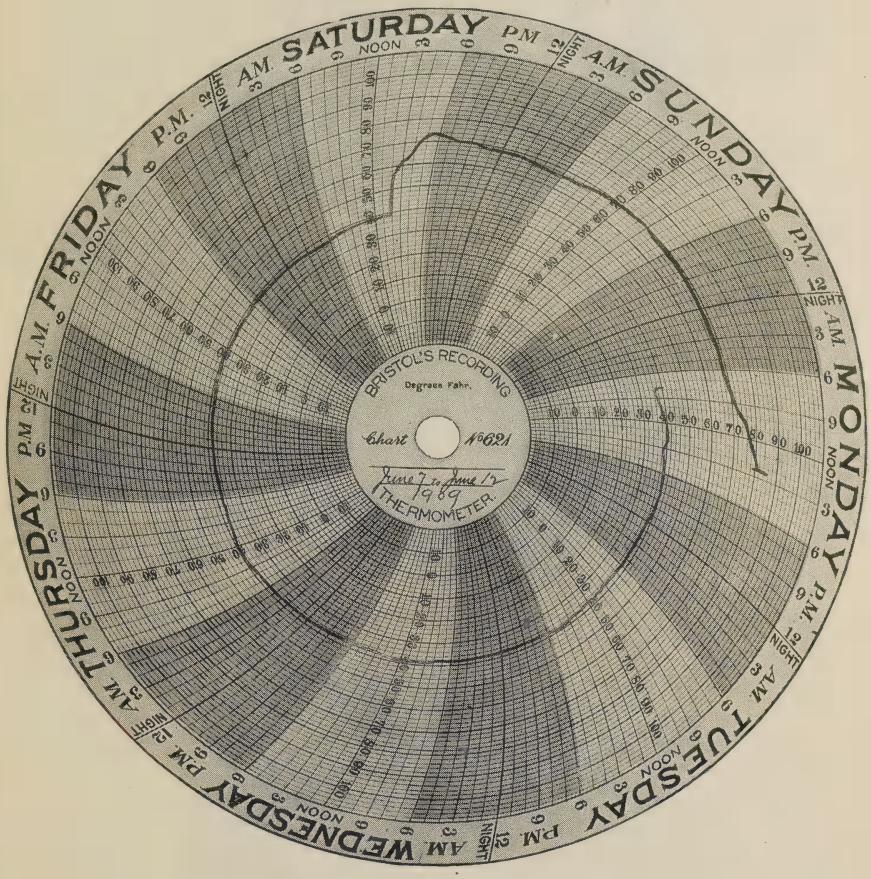
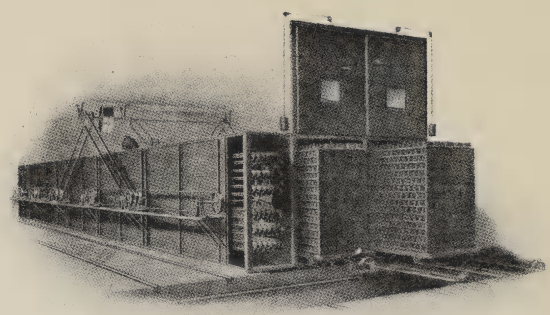
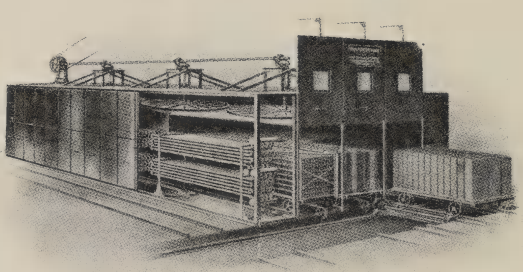


FIG. 19. Chart taken from the recording thermometers at the discharge of a Carrier Dehumidifier equipped with automatic dew-point regulation. Note the splendid regulation.

period, it is possible to crack them after shrinkage has stopped with the best known care being taken before that time.

17. In localities where high natural humidities (causing very much delayed drying), are regularly encountered for con-





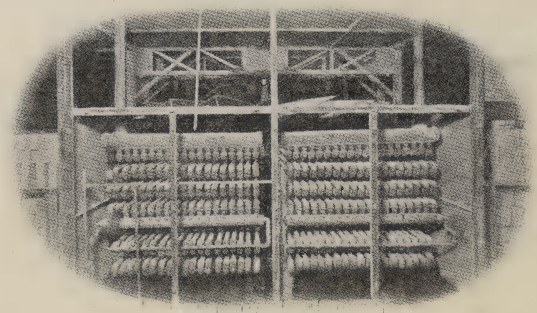
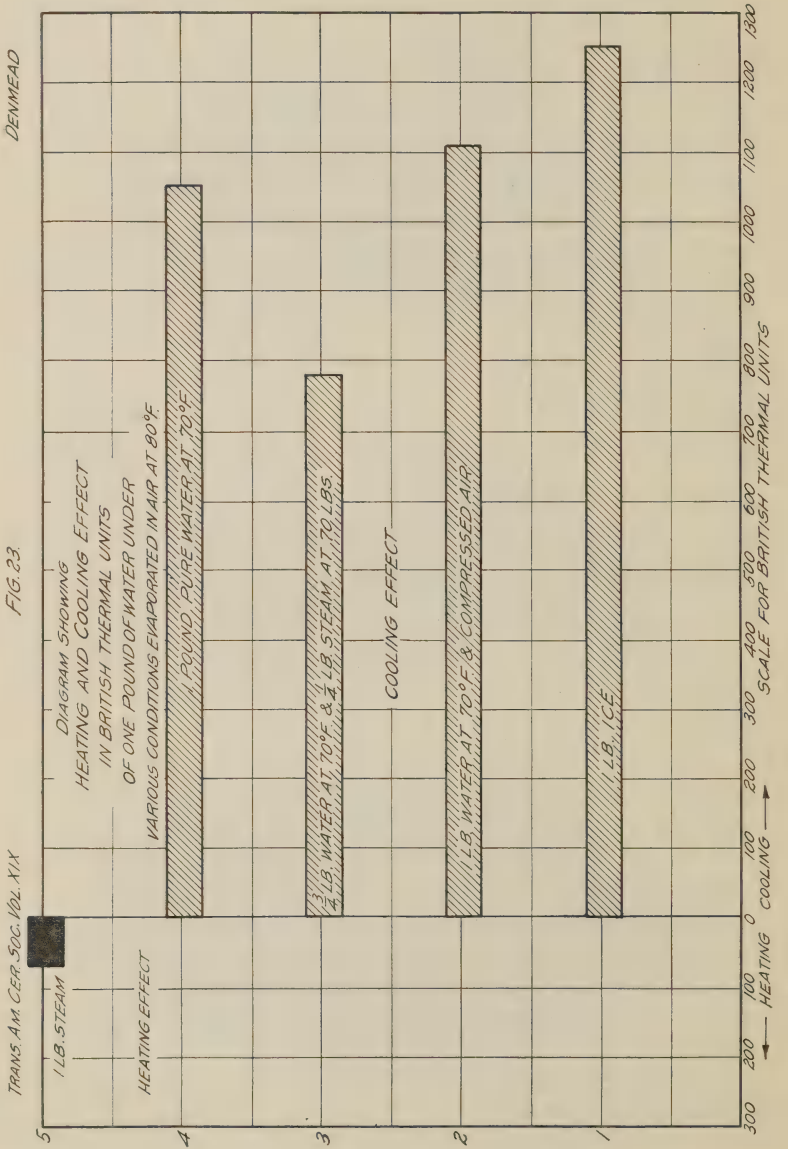


FIG. 20, 21 and 22. Copper plate showing three views of a drier employing the principles of humidity control.

siderable periods in summer, the possibilities of de-humidifying the drying room air for first-stage drying would seem worthy of investigation. Very large areas could not be economically dehumidified, but a room so controlled for the production of ware for rush delivery or for parts which cannot be moved to the drier until after some drying is accomplished, seems entirely feasible. A large number of plants in many lines of manufacture are so controlling certain rooms very successfully.

The writer would like to add in closing that the possibilities of such drying are very great, for though the claims of some of the drier concerns may seem extravagant, and perhaps are, there are possibilities even beyond their claims. In the course of a year many clay workers visit our plant and a great majority of them are looking for one means or another of hastening the delivery of finished products, and we find them considering many expensive schemes of plant rearrangement, continuous kilns, new machinery, etc., to save in some instances only a day or two. It would seem that the most likely method of facilitating production is being overlooked, namely, hastening drying by properly controlled conditions. I met one gentleman last year who advised that there was a period the previous summer when drying was practically at a standstill for nearly six weeks, and I am sure his ware could be safely dried in one week after proper conditions are ascertained. To demonstrate the point, on a number of occasions we have succeeded in safely drying in 12 hours one of our most difficult pieces which often shows considerable loss in air drying for one month under conditions which we believe are more carefully controlled than in the average plant. Though we do not know as yet just the proper handling to accomplish quite such rapid drying, it has been done repeatedly, and we know that the relation between humidity and temperature and the proper degree of each are the controlling factors. The results are not freaks, and there is no doubt, that with a fuller understanding of the factors, the results can be reproduced at will, though perhaps drying in quantity may cause difficulties that will make 12-hour drying impractical.


TRANS. AM CER. SOC. VOL XIX
FIG 23
DENMEAD
DIAGRAM SHOWING
HEATING AND COOLING EFFECT
IN BRITISH THERMAL UNITS
OF ONE POUND OF WATER UNDER
VARIOUS CONDITIONS EVAPORATED IN AIR AT 80°F
1 POUND PURE WATER AT 70°F
1 LB. STEAM
HEATING EFFECT
3/4 LB. WATER AT 70°F & 1/4 LB. STEAM AT 70 LBS.
1 LB. WATER AT 70°F & COMPRESSED AIR
1 LB. ICE
COOLING EFFECT
5
4
3
2
1
300 200 100 0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300
HEATING
COOLING
SCALE FOR BRITISH THERMAL UNITS

DISCUSSION

Mr. Stover: The subject matter of this paper is one that, what we don't know about, would make several volumes, and yet it is a thing we are paying for. I find that we have to go out of the clay industry to get data such as has been shown here, although the men who have put up apparatus for other industries guarantee 5, 6 and 12-hour drying of any piece of ceramics that they have ever heard of or seen, and if that should be true I think some of us would have to re-arrange our plans to get the thing in working order.

Mr. Barringer: It is true, there is no doubt about it, that the control of drying can be effected and that it means an enormous reduction in drying time. I think the subject is of sufficient importance to warrant the careful consideration of this Society.

Mr. Stover: I wanted to ask whether any of the members as an organization, or the Bureau of Standards, have made any investigation along this line? The question of not only getting the humidity and the temperature at the right point, but the question of pressure is one that is handled, more particularly in the foreign literature that I have been able to get. Some of the French and German and English works on this subject handle pressure in connection with humidity and temperature to great advantage. Have we any data from other members on this subject?

Mr. Barringer: In the humidity dryers that Mr. Denmead spoke of at the General Electric Company, which are only a stop on the road to the ultimate, we have been able to reduce drying from 8 and 9 weeks, to 1 week. I have seen magnesia bricks dried, they are being dried right along by the Harbeson and Walker Company in an enclosed dryer, and the reduction of time has been enormous. Here is a thing that has been the trouble of clay workers for years, and it is one of those things that have always been accepted as a necessary evil, and yet there is no stage of the art, no branch of the art for which we have available any more accurate or ingenious instruments than we have today. The people who have given attention to air

conditions for offices and for other industries are in position to furnish the clay workers with means of almost absolute control, and to have successful drying means absolute control. Absolute control means instruments of precision and exactness, and those I think we have. In passing, I should remark that this is a matter of exceeding importance.

Mr. Staley: I would like to ask Mr. Denmead how high you can get humidity in any commercial dryer without having condensation. We have experimented with dryers out at Iowa State College quite a little, and when we have tried to run the humidity up to say 80 percent humidity, always found we got some condensation on the ceiling of our dryers. I just want to know about how high you can run the humidity without getting condensation. It is possible that with better circulation that you do not have that trouble. We had considerable circulation, but whenever we got above 65 or 70 percent humidity, we found that we had condensation, which was worse than not having humidity.

Mr. Denmead: We have had the same conditions in Schenectady. I have claimed for a long time that it was very essential to move large volumes of air. I had to hurry through my paper so rapidly that I could not cover this point very much in detail; but the large fans are a recognition of the fact that there is danger of building up humidity higher at some points than at others. I might add that I saw a silk dryer in which existed a humidity of nearly 95 percent without any condensation at all, but enormous quantities of air were being moved.

Mr. Staley: You have to move every square foot of air in the dryer all the time?

Mr. Denmead: Originally in our work we had condensation all over the roof below 80 percent.

Mr. Watts: I would like to ask if there is not an enormous waste of heat in moving that large amount of air, or do you move it out into the factory and use that saturated air for something else?

Mr. Denmead: It is a very good proposition, but we are merely circulating the air in our dryer and letting it escape out through doors and windows, etc. In the Philadelphia machinery

dryer, where large fans are used, a means exists of taking away a small amount of the air all the time by small blowers. A small fan is removing a certain amount of air from the dryer and continually putting new air in all the time.

Mr. Staley: I would like to ask another question; I am very much interested in this proposition. I would like to ask if you can give any general idea of the size of the fan and the power that would be required, say in a 100-foot tunnel of a dryer heated by steam, to provide circulation? I have talked about this matter of circulation to several clay workers who have steam dryers. I said to them—"Why don't you buy a fan and circulate the air, take it out the roof and bring it around in the bottom again?" And they asked, "How much power will it take?" Well, I don't know.

Mr. Denmead: I cannot answer that question directly, though I did have some figures on a dryer that I am not free to give, but the power is very small in that case, because the fan is merely taking up air that is delivered to it under pressure.

Mr. Staley: What delivers it?

Mr. Denmead: Well, the first fan practically is taking nearly all the power.

Mr. Staley: The first fan takes how much power?

Mr. Denmead: It does not take anything like the power that would appear from all those fans.

Mr. Staley: Say you have a 100-foot tunnel and want to circulate the air in it; just as a guess, how big a fan does it require?

Mr. Blair: There was an operation at Lovett, Alabama, on the outskirts of Birmingham, 14 years ago, a brick dryer of this type. Probably Mr. Stevenson, who was interested in that, could give you information on it.

Mr. Staley: Owing to the enormous friction we have in blowing air through a lot of drying clayware, it takes a great deal more power than the blower companies figure.

Mr. Linbarger: We have been doing considerable work along the line which has just been explained and have found that in a manually controlled drying room we are able to maintain a higher relative humidity by the use of a steam jet than with

a water spray. I would like to ask what advantage there is in using water instead of steam in an automatically controlled humidity system.

Mr. Denmead: Steam immediately raises the temperature of the dryer and affects the control of your steam line through the automatic devices; steam being used for the purpose of humidifying often raises the temperature and makes the control much more difficult.

Mr. Linbarger: How great is that difficulty?

Mr. Denmead: It is great enough so that we have decided not to use it in our driers any more; we plan to use water entirely.

MEASUREMENT OF THE TIME OF SET OF CALCINED GYPSUM

BY WARREN E. EMLEY

The time of set of calcined gypsum, or of a prepared wall plaster made therefrom, is one of its most important properties. Pure $CaSO_4.\frac{1}{2}H_2O$ sets very rapidly. Commercially, however, the time of set is subject to variation, due to impurities in the gypsum, to the temperature of calcination, or to the addition of retarder. Under these circumstances, it is impossible to use the time of set as a criterion by which to judge the purity or proper calcination of the material. The time of set of calcined gypsum is far more important: it is frequently the determining factor which governs the suitability of a given plaster for a given purpose. For example, a plaster should not begin to set too soon, or its application would be a difficult matter; but having been applied, it should then set as rapidly as possible, in order not to delay the work. Obviously, any specification for calcined gypsum or wall plaster should cover the time of set. The writing of such specifications has been undertaken by Committee C-11, A. S. T. M., and as a necessary preliminary thereto, a standard method for measuring the time of set must be developed.

The time of set of any plaster is customarily divided into two periods, which may logically be differentiated as follows. For some time after the plaster has been mixed with water, it may be worked with impunity. Eventually, at the point of "initial set," it begins to harden. After this, any further working will destroy whatever bond has been formed, thus impairing the value of the finished product. Finally, the material will have undergone sufficient hardening so that it can no longer be worked, and is then said to have taken its "final set." With most plasters neither of these points is very sharply defined, so that it is deemed expedient to adopt some arbitrary means of determining them. For example, it would be very difficult to decide just when a sample of Portland cement had set sufficiently so that it could

no longer be worked. We can, however, determine when a needle of given dimensions will not penetrate it, and arbitrarily state that this shall be called the time of final set. To be acceptable, any such empirical designation must fulfill three requirements: (1) It must conform pretty closely to what is generally conceded to be the time of set of the material both from a scientific and a practical viewpoint. (2) It should be simple, so that the test will not be too costly. (3) It must be universally adopted.

The mechanics of the setting of calcined gypsum is so well known that it needs no explanation here. One point should, however, be called to your attention: the tremendous effect of small amounts of foreign material in the water and sand. If a contractor in a certain locality desires a plaster which will set on the wall in from four to six hours, the manufacturer may give him a calcined gypsum which when mixed neat with distilled water will set in forty minutes. The manufacturer must thus be familiar with the qualities of sand and water in his markets, and allow for them. Obviously, such anomalous conditions are not conducive to free intercourse, because if the above contractor asked a manufacturer who was unacquainted with local conditions for a gypsum plaster which would set in four hours, the material received would probably not fulfill his requirements.

Many methods of measuring the time of set of calcined gypsum have been suggested, and most of them are in use, with the result that it is difficult to find any two people who agree as to the time of set of a given sample. Recently a sample of plaster was thoroughly mixed and divided into five parts, which were sent to five different manufacturers. Each one determined the time of set by the method he is accustomed to use. The results varied from 16 minutes to 93 minutes. It is for the purpose of learning, if possible, which of the methods is best adapted to this material, that the present work was undertaken.

The methods in use may be grouped as follows: A — Methods based upon the measurement of the actual strength or hardness of the material at different time intervals. B — Methods based upon the measurement of some concurrent phenomenon such as the rise of temperature, or the expansion. C — Rule of

thumb methods, which were originally devised for plant control, but have frequently found their way into specifications.

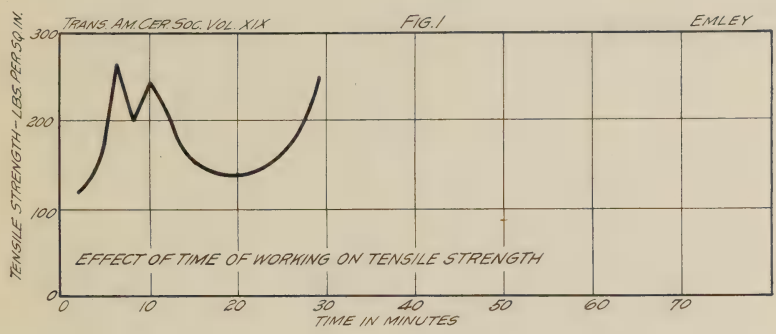
For the experimental work, a large sample of pottery plaster was mixed and stored in an air-tight container until used. It was extremely lean and slow setting, and therefore very well adapted to the work. The experiments reported in a paper by Kerr[1] called attention to the necessity of using the same consistency throughout, if the results are to be at all comparable. Since the same quality of plaster was used for all experiments, uniform consistency could be obtained by keeping the proportions of water and plaster constant. It was decided to use a rather thin consistency so that small errors in weighing the materials would have no effect. The following procedure was maintained constant for all experiments: In a perfectly clean porcelain casserole, put 65 cc. of distilled water. At a definite noted time, which shall be designated hereafter as zero time, 100 grams of plaster was added to the water as quickly as possible. This was permitted to soak for one minute, and was then stirred vigorously with a glass stirring rod for one minute. Thus the sample was ready for use exactly two minutes after zero time. Extreme care was taken to see that all traces of set plaster were removed from the casserole and stirring rod after each experiment. The molds were cleaned thoroughly, and then dipped in melted paraffine just before using. A stirring rod is to be preferred to a spatula or trowel for many reasons: its use precludes the possibility of chemical or electrical action; it is more easily kept clean; the plaster and water can be stirred into a homogeneous mass without the "working" effect, which is necessarily attendant upon the use of a larger blade.

Under Group A, the first method to be examined is the strength measurement. This method is the only one which can be regarded as absolute rather than empirical. If a point of time can be found such that any further working of the sample beyond that point will cause a diminution of strength, that point is by definition the time of initial set. Unfortunately, the method is far too laborious, and the results too indefinite for general use, so that it is of value only for judging which of the empirical methods

[1] *Trans. Amer. Cer. Soc., XVIII,* 1916.

comes nearest to the truth. The experiment was conducted as follows: A sample of plaster and water, mixed as above described was permitted to stand for X minutes. It was then reworked by mixing vigorously with a steel spatula, and cast into three briquettes. One hour after zero time, the briquettes were removed from the molds and put into a drying oven at 40° C. Twenty-four hours later, they were removed from the oven, and tested immediately. X was varied by one minute intervals from 2 minutes past zero time till the material was no longer workable. The results are shown in Fig. 1 and the remarks on the accompanying phenomena in Fig. 2. The immediate increase to a maximum is probably due to the thin consistency used; for the first four minutes, the plaster settled out of the mixture so rapidly that an undue proportion of it remained in the dish after the briquettes had been cast. This tendency becomes less marked as the plaster begins to thicken. For example, in the 5 minute sample the strength of the three individual briquettes were 120, 206 and 317 pounds per square inch, indicating conclusively that the mixture was not homogeneous. The 9 minute sample showed strengths of 191, 212, 217, showing that the mixture had thickened sufficiently to keep the plaster from settling out. In view of these results, it is possible that the depression shown at eight minutes may be due to experimental error. The curve shows clearly that the time of initial set for this plaster is 10 minutes, because if the sample is worked after this time, it loses strength. The time of final set is shown by Fig. 2 to be 27 minutes. The plaster can be worked after this time but not satisfactorily; the briquettes made at 28 and 29 minutes had rough surfaces and were ragged and full of holes. Fig. 1 shows that these last two samples were stronger than those preceding them. This is probably because the damp powders were packed into the molds with considerable force in an endeavor to make a presentable specimen.

The next four experiments were conducted to examine the "penetration method." The Vicat needle is 1 mm. in diameter, and weights 300 grams. Curve 1 in Fig. 3 shows how far this needle will penetrate into the paste by its own weight after given intervals of time. It will be noted that this method shows no indication of any initial set at 10 minutes. It shows very sharply


TRANS. AM. CER. SOC. VOL. XIX
FIG. 1
EMLEY
TENSILE STRENGTH - LBS. PER SQ. IN.
300
200
100
0
EFFECT OF TIME OF WORKING ON TENSILE STRENGTH
0
10
20
30
40
50
60
70
TIME IN MINUTES

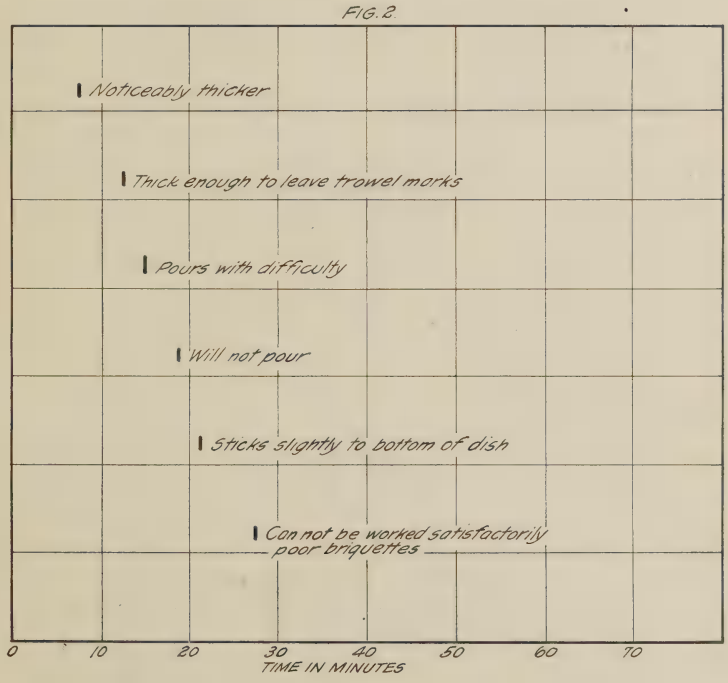


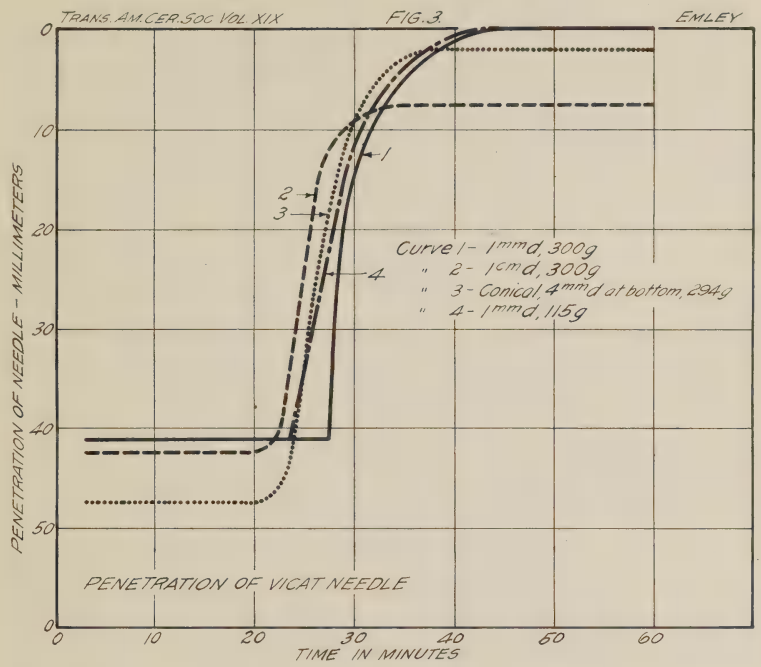
FIG. 2.
Noticeably thicker
Thick enough to leave trowel marks
Pours with difficulty
Will not pour
Sticks slightly to bottom of dish
Can not be worked satisfactorily
poor briquettes
0
10
20
30
40
50
60
70
TIME IN MINUTES

and distinctly the point of final set at 27 minutes. It shows also another rather indefinite point at about 45 minutes, when the needle will make no impression on the surface of the plaster.

Curves 2, 3 and 4 in Fig. 3 were produced by changing the size, the shape, and the weight of the needle, respectively. Apparently with these needles, the final set occurs in less time. Fig. 2 tells us that this is not so, and therefore the regulation Vicat needle (Curve 1, Fig. 3) is best adapted to the material. There is no indication of any initial set shown by any of them.

Under Group B there are two general methods, based upon expansion and temperature rise. We know that calcined gypsum expands as it sets, and a measure of the rate of expansion should therefore measure the rate of set. A thin walled rubber bulb was filled with water and placed in a small heavy metal can. The can was then filled with a sample of plaster and water mixed as above described. The cover was then screwed on until the plaster came out through two holes in it, so that the can was completely filled. Through one hole in the cover protruded the stem of the bulb, which was connected to a vertical glass tube. The other hole served to introduce a thermometer into the plaster. As the plaster expanded it squeezed the water out of the bulb and made it rise in the glass tube, where its height could be read. The thermometer was read simultaneously, and the height of the water corrected for the expansion due to heat. The final results are plotted in the curve, Fig. 4. This curve also shows no initial set. It shows the final set at 27 minutes, but not so sharply and definitely as curve 3, Fig. 3.

Heat is generated by the chemical reaction which causes the set of gypsum. This causes the temperature of the mass to rise, and the rate of the rise of temperature should therefore be an indication of the rate of set. This method has been more widely used and more thoroughly investigated than any other, but it seems that one of the basic principles has been overlooked. The speed of any chemical reaction is either retarded or accelerated by an increase of temperature. Assuming that the method of manipulation is so refined as to prevent all loss of heat by radiation, then a large sample of plaster will generate more heat than a smaller one, but it will also have a larger quantity of material


TRANS. AM. CER. SOC. VOL. XIX
FIG. 3.
EMLEY
PENETRATION OF NEEDLE - MILLIMETERS
0
10
20
30
40
50
0
Curve 1 - 1mm d, 300g
" 2 - 1cm d, 300g
" 3 - Conical, 4mm d at bottom, 294g
" 4 - 1mm d, 115g
1
2
3
4
PENETRATION OF VICAT NEEDLE
0
10
20
30
40
50
60
TIME IN MINUTES

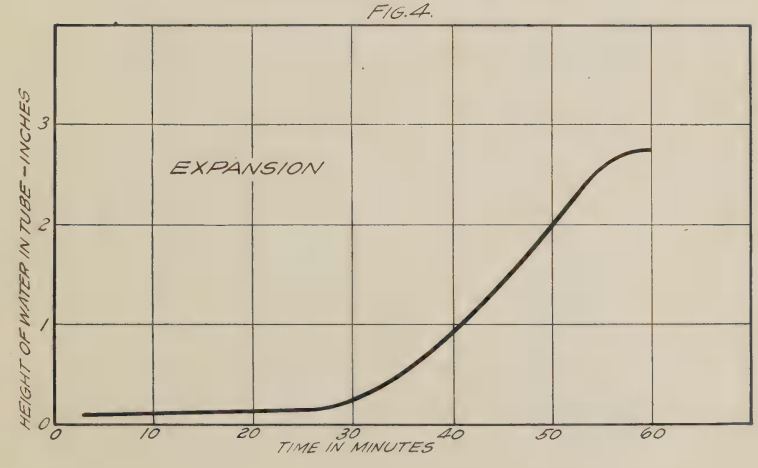


FIG. 4.
HEIGHT OF WATER IN TUBE - INCHES
0
1
2
3
EXPANSION
0
10
20
30
40
50
60
TIME IN MINUTES

to heat. The final temperature will depend upon the balancing of these two factors. Without attempting to discuss whether a large sample will give a higher or lower temperature than a small one, we may be reasonably certain that the two temperatures will not be the same, even under ideal conditions. Practically, the sample is always subject to more or less loss of heat by radiation, so that the temperature as read really indicates the difference between the rate at which the heat is generated and the rate at which it is lost by radiation. Therefore the maximum temperature is a function of the shape and size of the specimen, the difference between the temperature of the specimen and that of the air and other similar factors which govern the radiation of heat. It is logical to assume that the absolute value of the temperature at any time will have some influence on the speed of the reaction, and therefore on the rate of set, at that time.

The curves 1, 2 and 3 of Fig. 5 show the effect of the size of the sample on the rate of temperature rise. They were made by inserting a thermometer in the center of a one inch, two inch, and three inch cube respectively. The molds were made of paraffined paper, and care was taken to keep the factors governing radiation as nearly constant as possible. It will be noted that curves 1 and 2 show maximum temperature at 45 minutes, while the rate of set of the 3 inch cube is somewhat retarded. The size of the specimen evidently makes little difference, provided it is not too large. It is suggested that a good design would be a cylindrical specimen of such a size that the bulb of the thermometer would be equidistant from the surface. For example, if the bulb of the thermometer is $\frac{3}{4}$ in. long by $\frac{1}{8}$ in. diameter, the specimen might be made $1\frac{3}{4}$ in. long by $1\frac{1}{8}$ in. diameter, and then every point on the surface of he bulb would be just $\frac{1}{2}$ in. from the surface of the specimen. A mold of this shape can be conveniently made by cutting a piece of paper of the required dimensions, dipping it in melted paraffin, rolling it to shape, and mounting it on paraffin on a glass plate.

Specimens of this shape were used in curves 4 and 5 in Fig. 5, which show the effect of variation of initial temperature.

Three points are to be noted from these five curves: (1) Initial set occurs before there is any noticeable rise of temperature. (2) At the time of final set, the temperature has begun to rise, but there is no sharp break in the curve to indicate a sudden change in the rate of reaction. (3) There is a well defined point of maximum temperature, which has frequently been called the time of set. If, however, we define final set as the time after which the material is no longer workable, this point of maximum temperature occurs considerably (with this plaster, 18 minutes) later than the final set. It does not mark the completion of the chemical reaction, for we know that the specimen will continue to increase in strength for days. This point can only be interpreted as the time at which the reaction reaches its maximum velocity. The point is undoubtedly of scientific interest, but inasmuch as the plaster has long before ceased to be workable, it is difficult to see how this point can have any practical significance. Certainly it is a misuse of terms to call it the time of set.

Only one conclusion can be drawn from the above experiments: The measurement of the temperature rise is useless for determining the time of set.

In Group C are included a number of empirical methods, the results of which are shown in Fig. 6. None of these requires any especial explanation, except that the standard German method for measuring initial set is when the knife leaves a clean cut; and for final set, when the shavings come off grainy and brittle. The number of methods in this group could be multiplied indefinitely, since almost everyone dealing with gypsum has a pet method of his own. The seven methods given were selected as being typical, and since none of them shows the remotest connection with the time of set, either initial or final, it is hardly worth while to go further.

From the above discussion it seems reasonable to draw the following conclusions: (1) None of the methods examined is capable of indicating the initial set. (2) The ordinary Vicat needle, 1mm. in diameter, weighting 300 grams, is eminently satisfactory for measuring the final set. (3) There is a third point, indicated by the temperature curves and

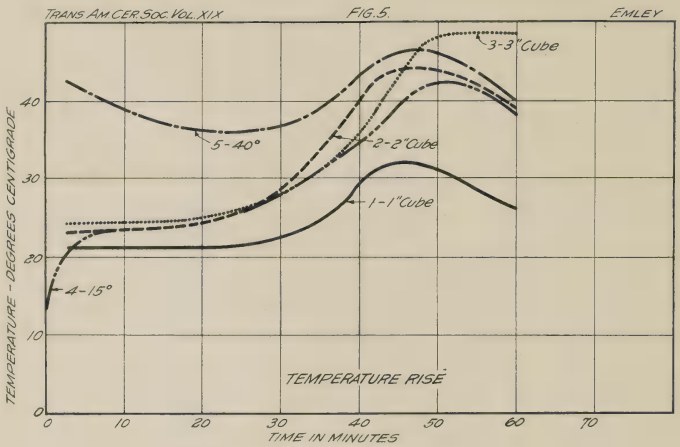
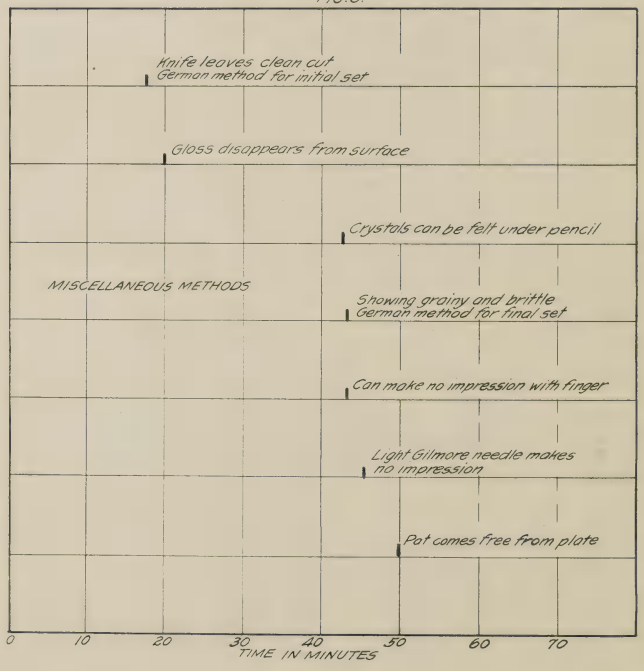

TRANS. AM. CER. SOC. VOL. XIX
FIG. 5.
EMLEY
TEMPERATURE - DEGREES CENTIGRADE
3-3" Cube
2-2" Cube
1-1" Cube
5-40°
4-15°
TEMPERATURE RISE
0
10
20
30
40
50
60
70
TIME IN MINUTES

FIG. 6.


Knife leaves clean cut
German method for initial set
Gloss disappears from surface
Crystals can be felt under pencil
MISCELLANEOUS METHODS
Showing grainy and brittle
German method for final set
Can make no impression with finger
Light Gilmore needle makes
no impression
Pat comes free from plate
0
10
20
30
40
50
60
70
TIME IN MINUTES

by some of the methods in Group C, which is apparently the time of maximum velocity of setting. This point is of doubtful practical value.

Referring to Fig. 1 we find that when plaster is worked after it has taken its initial set, its strength is somewhat impaired. Fortunately, however, it does not seem possible to decrease the strength below ordinary practical requirements. That, is, for most purposes for which gypsum is used, it could make little difference whether its tensile strength is 250 pounds per square inch or only 125. Indeed, experience leads one to believe that in most cases initial set has taken place before the application of the plaster has been completed. In other words, the working of a gypsum plaster makes no serious difference in its properties up to the time of final set when it can no longer be worked. From a practical view point, therefore, the measurement of the time of initial set is unnecessary, the final set only being of importance.

This interpretation of results may be objected to by one familiar with the testing of Portland cement. By such a one, the first break in curve 3, Fig. 3 would be taken as indicating the time of initial set, instead of the time of final set, as it has here been designated. In answer to this objection, it may be stated, first: The definition of either initial or final set, when measured by a penetration method, is purely empirical. There is, therefore, no particular reason for following the definitions adopted by the cement industry, when there is any advantage to be gained by deviating from them. Second: If it is accepted as logical that final set has occurred when it is no longer physically possible to work the material, then a comparison of Figs. 1, 2 and 3, will be convincing that the first break in curve 3, Fig. 3 corresponds to the time of final set.

Based on the above information, the following method is recommended for determining the time of set of calcined gypsum or of prepared plaster made therefrom. Determine first the normal consistency using the Southard instrument, as recomended by Sub-committee 4 of Committee C-11, A. S. T. M. Determine from this the amount of water which must be added to 100 grams of the sample to produce a paste of

normal consistency. In a perfectly clean porcelain casserole, put three times this amount of distilled water. Weight out 300 grams of the sample and transfer to a clean sheet of glazed paper. Also provide a clean glass stirring rod about $\frac{1}{8}$ in. diameter? When the second hand of a watch points to zero, transfer the sample from the paper to the casserole. This should be done as quickly as possible without splashing, and should not take more than two seconds. Let the plaster soak quietly until the second hand again reaches zero, when the mixture is to be stirred vigorously by means of the stirring rod for one minute, by which time the mass should be homogeneous.

At the end of the second minute, this mixture should be poured into the mold for the Vicat needle. At one minute intervals, the needle is allowed to sink into the paste. Eventually there will be found a time when the needle will not penetrate clear to the bottom. The time elapsed between the time when the sample was added to the water and the time when the needle no longer penetrates to the bottom is recorded as the time of set.

The sample, water, casserole, and mold shall be at a temperature of not less than 20°C., nor more than 25°C. at the beginning of the experiment.

The Vicat needle and the mold are described in the standard specifications for cement — 1915 Year-book, A. S. T. M., page 359. The mold is made of hard rubber, and it will be found difficult to remove all traces of set plaster from it without scraping, which might cause injury. To overcome this, the mold should be prepared for use by dipping it in melted paraffin. This will prevent adherence of the plaster to a great extent, and the mold can be cleaned thoroughly and easily by heating it very gently.

RECENT IMPROVEMENTS IN METHODS OF TERRA COTTA MOLD MAKING

BY R. B. KEELER

Since the introduction of architectural terra cotta in this country, the art of making the plaster molds has followed along the same general lines regardless of cost or economy of plaster. The model of the unit wanted is made first, and over this is cast the mold. The model is then discarded and is considered an absolute waste after the mold has been cast over it.

To avoid the waste of labor and plaster in models, if only for the simplest forms of terra cotta units, means considerable saving, and recent successful attempts have solved this problem by producing molds without the aid of the plaster models and has been patented by J. W. Pemberton, May 16th, 1916, as "Method of Mold Making."

The ashlar block is the simplest form we have, and yet it represents about one-half of the product of the terra cotta business. In the present method of mold making with the aid of a plaster model, the sides and ends are cast first, and the face is made last. In the new method the process is reversed, the face is made first, the sides next and the ends last.

To cast the face: Mark on the smooth table top (as used in the plaster shops of factories) the size of the ashlar desired, using a square and pencil, as is now done in casting ashlar models.

Place four angle bars "A" on these lines as illustrated by Fig. 1, and then clamp. The clamping device shown in Figures 15 and 16 insures perfectly square angles on all four corners of the ashlar face.

Grease the table top inside of the bar "A" and pour the box thus formed, full of plaster. The operation should take less than ten minutes. As soon as the plaster has set the bars are removed, and the cast is turned over. Figure 3 illustrates the finished face.

It may be seen from the section of bar "A" as shown by Figure 2, that the joggle holes as well as the chamfer are cast directly with the mold face in one operation, whereas in the old method these are all cut by hand work. Another point which bears consideration is the uniform thickness of this face, thus establishing the minimum amount of plaster necessary for a strong mold. By the old process the mold faces were often made thicker than is necessary thus wasting considerable plaster, in fact, no two mold makers make their molds the same thickness.

The mold sides are formed by two adjustable boxes (Figure 7,) which rest at either side of the mold face. The mold side casting boxes are simply set in place (see Figure 7), clamped and poured full of plaster. The operation should take less than ten minutes. See Figure 8 for finished face and sides.

The mold side casting box is composed of three units, bar "B" (see Figures 4 and 5) which is grooved on one side for producing a mortar bed and smooth on the other side producing a smooth sided mold, end stops (see Figure 6) which form the offset and joggles at ends of mold sides, and a pouring board which acts as a retainer for the plaster as it is poured to form the side.

For various heights of ashlar, the bars "B" may be made in any height from 4 in. to 12 in. etc., the same may be said of the pouring board "D". The height of the end stops "C" may be increased by small blocks set and clamped on top of the bottom unit. See Figures 11 and 11a. These small blocks may be made in various heights for 6 in., 8 in., 10 in. or 12 in. ashlars as the case may be. If a finished mold side is wanted, the smooth side of bar "B" is turned out to be cast against. See Figures 9 and 10. The end stops have detachable backs which form either smooth sides, continuous mortar bedded sides or panelled mortar bedded sides as are used adjoining a finished end.

The mold ends are formed by the bar "E" (See Figures 12, 13 and 14), which, like bar "B" (See Figure 4), is made to produce either a mortar bed end or a finished end and is cut into various lengths suitable for different widths of ashlar. These sectional bar pieces are fitted in between the two sides that are already cast, and if the given bar sections do not fill the width

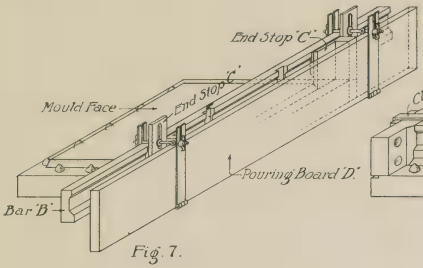


Fig. 7.

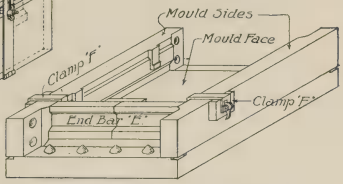


Fig. 8.

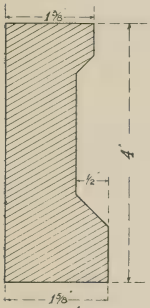


Fig. 4.

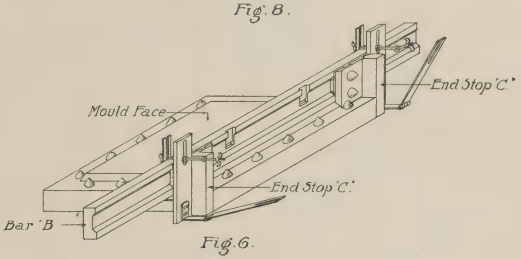


Fig. 6.

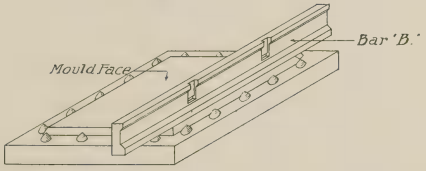


Fig. 5.

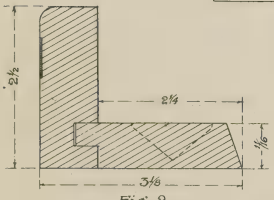


Fig. 2.

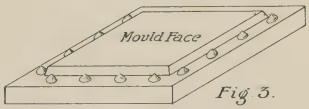


Fig. 3.

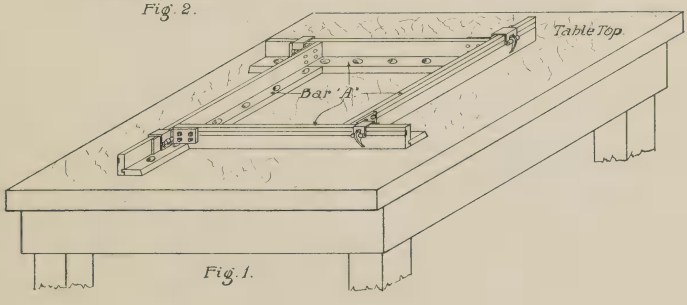


Fig. 1.

between the sides, less than one inch, the distance is made up by clay filled in between and scraped clean to follow the profile of bar "E" (See Figure 8). To hold bar "E" in place the clamps "F" are fastened behind it (See Figure 8), and the pouring board "D" set in position. The mold ends are then poured, and the process is completed giving a finished mold. The last operation should not exceed ten mintues.

The pouring board "D" may be omitted if it is the custom of the factory to throw up the plaster sides or ends by hand. In some factories it is considered more profitable to pour the sides and ends, in fact, the quality of the plaster used, prevents much working by hand. In other factories it is considered a much stronger job if the sides and ends are thrown up by hand.

From the foregoing remarks it may be seen that the entire process consumes not more than thirty minutes, if the mold maker keeps the bars and stops in systematic order and quickly accessible, has his clamps in good working order so they may lock into place with one motion, and finally calculates his movements in advance so that while a newly poured face is setting, he may cast the sides or ends on a previously cast face.

Stop blocks and extra ends are formed by moving bar "E" further into the mold after ends have been cast, and recasting the stops or ends as required. This takes about one-half the time to produce stops or extra ends over the old process.

General Remarks. Mold faces when worn may be renewed by planing or scraping them down until they are again smooth and level thus utilizing them over and over again until broken or too thin to use. The mold faces made by the old process are good for perhaps one hundred pieces or until the face becomes too pitted for use; they are then discarded. With the new process the mold faces are set aside in order according to their size, the dimensions being marked on one edge and all faces standing vertical to be readily accessible. As orders for ashlar molds come in, the sizes nearest the ones desired are selected from those in stock, leveled up and new sides and ends are cast to fit the size desired. The sides and ends may be cast to any dimensions on the old mold face as long as the mold face is within an inch or two of the right size. It may be readily

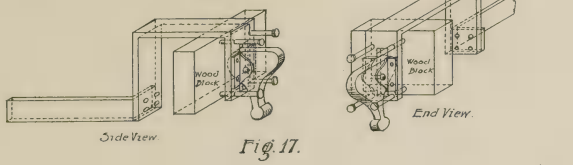


Fig. 17.

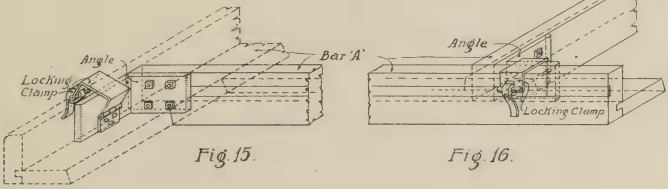


Fig. 15. Fig. 16.

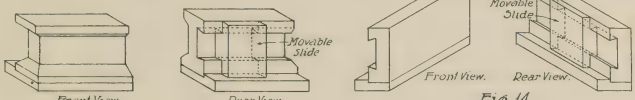


Fig. 13. Fig. 14.

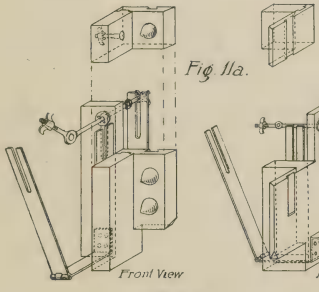


Fig. 11a. Fig. 11.

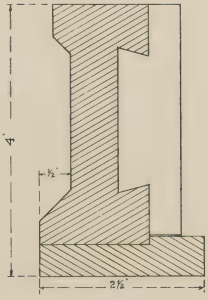


Fig. 12.

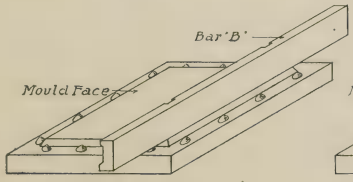


Fig. 9.

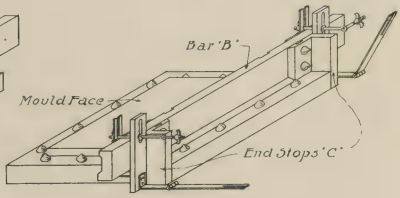


Fig. 10.

seen that even a thousand pieces could be pressed by renewing an old face ten times, showing considerable economy both in labor and material over the old process.

It may be said in favor of the new process that an average model costs between sixty and seventy-five cents for labor and plaster besides the original investment in casting bars which form the model, and this expense is entirely eliminated by the omission of the model from the new process.

In some factories an average mold maker produces three ashlar molds per day by the old process from different sized models. His wages amount to $2.75 per day or a cost of 92 cents each for labor plus 60 each for models, total $1.52 per mold not including the cost of plaster which is in the mold. Figuring that this is about as slow as molds are usually made, which is at least half the time of the average mold maker, we may take it for granted that this class of labor will produce one mold per hour or nine per day with the new process at a cost of 30½ cents each per mold not including the cost of plaster, no model being necessary. This represents a saving of 80 percent over the old method.

In factories where the mold makers work rapidly, producing eight molds per day at a $3.00 per day wage, the cost by the old process amounts to 37½ cents per mold for labor and 60 cents each for models totaling 97½ cents each, not including the cost of plaster in the mold. Considering labor at this speed we assume that fifteen molds per day can be produced by one man, being paid at the rate of $3.00 per day, by the new process or a cost of 20 cents each, not including the cost of plaster in the mold. This represents a saving of 79 percent. From actual tests the cost of stop blocks is cut in two. The new system still has the advantage of the repeated use of the worn mold faces.

The cost of an outfit for producing 4 in. ashlars would be around $50, depending entirely on the cost of material and the skill of the mechanics working upon it. The wood work should be preferably poplar thoroughly seasoned and soaked in hot linseed oil after being scraped and glued. The outfits are practically indestructible and will last a life time under ordinary usage. The additional cost of stops and bars for a 6 in. ashlar will amount to

$10 in fact, and $10 for each different height of ashlar to be made.

Other possibilities: Where but a small number of molded pieces with a four, six or eight inch reveal are required, it is often possible to run small moldings nailing them securely to the face of the ashlar. This saves the expense of making large zinc templets and wooden horses (frames to hold templets) and above all the expense of building up clay forms on the running table and the wages of two men in running a large templet. This is adopting the method employed by the artificial stone manufacturers *i. e.* making square molds and nailing various moldings inside, to form architectural profiles, the only difference being that the artificial stone manufacturers use wood, and the terra cotta manufacturers use plaster.

There are a great number of molds now used in the terra cotta industry which would fall under this head; on the other hand there are a great number of molds which must be produced by the old method, owing to the character of the ornament, etc. Men in charge of the departments should divide the work into the two classes giving the work best suited to the old method to the men most familiar with this class, other work to be given to the men most familiar with the new class. If this rule is followed there will be little or no confusion resulting from a subdivision of the work. Where but one model is needed for a large number of molds, the old system is equal to the new as one man can produce as many as fifteen molds per day under very favorable conditions.

The new system is now being applied to large running molded sections. The molded portion of the model is run in plaster in the usual way on a table top and is measured for length, stopping the profile at either end with strips of clay to produce a chamfer. The face profile is then cast the same as any mold face. The sides are cast against thin metal plates which may be adjusted for any height and will produce either mortar bed or smooth faces. The ends are built up in clay as is done at the present time with plaster models, and the ends of the mold are cast against these.

As the application of the new system to various molded pieces is still in the experimental stage, it would be well to publish in our next Transactions the final conclusions. As it is, the process looks quite possible for most plain moldings no matter how large or how small.

The contour of the table top naturally governs the contour of the mold face, which is cast upon it, therefore, in many cases it is possible to make on a thin slab of plaster certain moldings or marks which may be cast directly into the face of the mold. The bars "A" may be placed around any object or objects to form the mold face. For instance, large letter panels may be produced by casting the letters in plaster and over them running a profile just enough to cover the letters.

The letters are then removed from the running which is cut up into various lengths according to desired jointing of the letters. The longest running is then selected, and an ashlar mold is made over this slab. Then a movable stop block is made to conform to the various length of lettered pieces.

The separate lettered pieces are then dropped one at a time in the mold and pressed thus forming a perfect raised-letter panel.

The countersunk letter paneds are made by nailing plaster letters on a slab similar to the above using the same form of mold throughout. This process of producing letter panels is considerably simpler than the old way and insures more perfect letters also giving a mold for each piece so in case of breakage another piece can be pressed without loss of time. It keeps the cutting of letters entirely out of the miter cutter's hands, sending the molds directly to the pressing department thus insuring speed as well as less expensive labor.

There are so many ways of employing the new system that perhaps a volume may be devoted to it. Let us hope that those interested in improving factory systems and cutting costs will take up methods along these lines, comparing figures and contributing their views to the Transactions.

CAUSES FOR THE FAILURE OF TERRA COTTA IN THE WALL

BY R. L. CLARE

The failure of a piece of terra cotta in the wall is taken to mean that the piece becomes cracked, chipped or broken, or that the glaze or slip coating shows crazing, shivering, peeling, or other similar defects, after the piece has been set in the building. In fact any piece that has, or develops, any defect that would cause it to become either unsightly or unsafe, after it has been set, should be classed as defective.

It is natural that the terra cotta manufacturer is very much interested in the causes for such failures in order that he may correct them if they arise in the plant, or that he may place the liability elsewhere if the failure is due to conditions not under his control.

The first and most important cause of failure is a defective body mixture. Such a mixture gives rise to numerous defects in the ultimate burned piece, and these defects are in most cases developed or exaggerated by the weather. As a result it has been common practice to state that the weather, meaning the action of heat and frost, caused such pieces to fail, whereas this action is only the secondary cause of the failure, with the primary cause originating within the factory itself. Such pieces undoubtedly are sent to the building with some physical defect or strain, either unnoticed or undeveloped and hence the failure. Our tests have indicated that the average piece of terra cotta, without defects and as it is now made, is of sufficient strength to resist any action of the weather.

It is not feasible to give reasons as to why a mixture is defective, as each mixture must be designed to suit the local conditions in each plant, and a good mixture in one plant may be a poor one in another. It is possible however to give some of the defects which result in failures in the wall from this cause, as follows:

First — Fire cracks or cooling cracks.
Second — Drying or shrinkage cracks.
Third — Low absorption or too dense a body.
Fourth — High absorption or too weak a body.
Fifth — Excess of soluble salts.
Sixth — Iron pyrites, lime pebbles or other such impurities.
Seventh — Low bonding power.

A body with a tendency to any one or more of the above named defects will develop those defects in pieces which receive slight variations from the normal treatment, such as being pugged poorly, dried too rapidly, or cooled too quickly. The proper body should stand these ordinary variations in treatment without serious results.

Another cause for failure of terra cotta pieces, and one that ranks next in importance, is the defective glaze or slip coating. The proper coating, as in the case of the proper mixture, should stand the normal variations in firing and cooling without developing defects or strains which the subsequent action of the weather would bring out. Some of the defects arising from this cause are:

First — Crazing.
Second — Shivering.
Third — Peeling.
Fourth — Separation of vitreous coatings.
Fifth — Soft or porous coatings.

The occurrence or tendency to occur of any of these defects, gives the weather an opportunity to develop and aggravate them to a point where the piece becomes defective and is said to have failed. In this as in the preceding case, the weather is only the secondary cause of the failure.

The next cause for failure, and one to which too little attention is given in the average plant, is irregular burning conditions. This is taken to include setting, firing and cooling. No matter how good the body mixture and glaze or slip coating may be, strains and defects are continually being formed at this period. Consequently the importance of control over this operation can-

not be too strongly urged, as oftentimes a few hours difference during certain periods in the rate of firing or cooling, or a slight change in the manner of setting, will prevent pieces from developing these strains which may eventually show up in the building.

The fact that terra cotta must be made in such widely varying shapes and sizes, and that the walls of the pieces are of such uneven thicknesses, makes this burning operation of more vital importance to the terra cotta manufacturer than probably to any other manufacturer of clay wares. Some of the defects arising from this operation are:

First — Shrinkage cracks.
Second — Under burned or overburned material.
Third — Fire cracks or cooling cracks.

The first two defects named are easily discernible and hence are not so dangerous, as they can be readily separated from the good material.

The last of these however, fire cracks or cooling cracks, is most important. These are usually so fine as to be unnoticeable before the material is shipped or, do not develop until after shipping when subjected to the additional strains arising in the building. These fine cracks constitute one of the most insidious defects, with which the terra cotta manufacturer has to deal, and should be investigated most carefully.

Nearly every terra cotta plant has kilns of widely different sizes and capacities. The writer has knowledge of kilns being burnt from 50 hours to 150 hours in the same plant and cooled over a like range. It is not probable that terra cotta burned or cooled in 50 hours is as free from strains or visible defects as the same material burned or cooled in 100 hours. Experiments which we have put through have shown that it is much easier to produce these fire cracks or cooling cracks by a slight change in the rate of firing and cooling than it is by changing the body composition over a very wide range.

The manner in which the material is set in the kiln might also be investigated as a source of this defect. One company within the writer's knowledge has eliminated to a large extent

the setting of pieces on top of others in the kiln which certainly would diminish the tendency to set up strains during the firing. A better control and regulation of these burning conditions should materially reduce the number of failures from this source.

Other causes for the failure of terra cotta pieces may be classed under the general heading of stresses set up in the building itself, entirely separate and independent of the quality of the terra cotta furnished. This of course is without the province of the ceramic engineer, but it is important to the manufacturer in order that he may show, in many instances, that it is faulty construction or faulty setting that has caused the failure of certain pieces of his material. Some of the causes for failure under this heading are:

First — Expansion, contraction, or deflection of steel framework to which the terra cotta is attached.

Second — Expansion, contraction, or other movement of reinforced concrete buildings to which the terra cotta has been anchored.

Third — Settling of foundations with the resultant strains transmitted to the terra cotta.

These three causes all result in the same class of defects, namely: cracked, chipped or broken pieces.

Fourth — Imperfect "backing up" or "filling" of the terra cotta and imperfect "pointing up" of the joints.

A piece of terra cotta with the voids filled with a very rich cement mixture is subjected to a severe strain by the expansion of this material.

If the setting is faulty, and the joints are not water-tight, water is permitted to get in behind the pieces and to collect in pockets, and the resultant expansion of this pocket of water when freezing is very liable to burst the piece.

THE CRAWLING OF MAT GLAZES

BY CHARLES F. BINNS AND MARY E. SAUNDERS.

Everyone who has worked with the ordinary type of mat glazes high in alumina has been confronted more or less with the phenomenon known as crawling. The glaze cracks in the process of drying, and the separated parts will sometimes fall off entirely or will fail to reunite upon fusion but will roll up and leave bare patches; or if the crack be healed a line of parting will show and cause the well known alligator skin surface. This is sometimes pleasing in appearance, but it is not always under control.

At the beginning of this study it was believed from an observation of occasional phenomena that the crawling might be due to one or more of the following causes:

1. The condition of the biscuit ware as to fire.
2. The use or non-use of a mucilage binder.
3. The source of the alumina in the glaze.
4. The grinding of the glaze substance.

A schedule of experiments was therefore laid out to cover these points. The glaze chosen was a practical mat glaze corresponding to the following formula:

$$\left.\begin{matrix} PbO\ .60 \\ CaO\ .25 \\ K_2O\ .15 \end{matrix}\right\} .35\ Al_2O_3.\ 1.30\ SiO_2$$

This was stained black by adding to the batch of glaze a mixture of cobalt oxide 5, iron oxide 4, and nickel oxide 3 parts.

A number of small vases were cast from an ordinary white body. Half of the pieces were burned to cone 02 giving a soft porous ware the other half to cone 3 giving a body of good density but still slightly porous.

After allowing for the alumina provided by the feldspar, the balance, amounting to .20 equivalent was introduced from

various sources, namely: 1, calcined Florida clay; 2, Tennessee ball clay; 3, raw Florida clay; 4, .05 raw Florida clay, .15 calcined Florida clay. Four batches of each mixture were prepared and were ground a half hour, one hour, one and a half hours, and two hours respectively. Half of each batch was used plain and the other half with a suitable amount of gum-tragacanth mucilage. The pieces were all soaked in water to saturation, wiped dry and glazed by pouring. The glaze burn was all the same, cone 01 in 22 hours.

A broad survey of the results offers evidence that the most important general factor in affecting the tendency to crawl was the burning of the body. This point appears to be new for no allusion to it has been found in any article dealing with the behavior of mat glazes. On some of the short-fired pieces the glaze fell off in large flakes, and the addition of mucilage did not suffice to prevent this. The factor of next importance was the grinding of the glaze. Most of the pieces with the half hour grind behaved well. An additional grinding increased the tendency to crawl, caused the glaze to flow during burning and tended to produce blisters. The use of mucilage helped a good deal, especially when all the clay content was calcined. The most perfect specimen of glaze was that made from calcined clay, ground one-half hour, mixed with mucilage and put upon a well-fired body.

A few pieces have been selected to illustrate the points set forth.

Vase No. 3. Hard body, calcined kaolin in the glaze, ground one-half hour. Mucilage used. Glaze good texture, no crawling.

Vase No. 6. Soft body, calcined kaolin in the glaze, ground one hour. No mucilage used. Glaze nearly all fallen off. Remainder blistered.

Vase No. 8. The same as 6 but with mucilage. The heavy coat of glaze has run and there is some crawling.

Vase No. 15. The same as No. 3 but the glaze ground two hours. Glaze good but slight tendency to flow.

Vase No. 25. Hard body, Tennessee ball clay in the glaze, ground one-half hour. No mucilage used. Glaze crawled, run and blistered.

Vase No. 17. Hard body, Tennessee ball clay in the glaze, ground one-half hour. No mucilage used. Glaze slightly run, crawled at the top.

Vase No. 46. Soft body, Florida clay in the glaze. Ground two hours. No mucilage used. Glaze crawled, run and blistered badly.

Vase No. 49. Hard body, Florida clay and calcined kaolin in the glaze. Ground one-half hour. No mucilage used. Glaze crawled very slightly, inclined to run.

DISCUSSION

Mr. Minton: I should like to ask Prof. Binns if the disk pieces were sandpapered on the surface before the glaze was applied?

Mr. Binns: No sir.

Mr. Minton: I know that that is a frequent cause of the crawling of glazes; there seems to be a surface factor which enters in there, and if the ware is sandpapered it will frequently overcome that defect.

Mr. Riddle: I would like to ask Mr. Binns what he thinks the different effects would be when spraying or dipping on a dry piece as compared to pouring the glaze on a saturated piece of ware?

Mr. Binns: I have no actual experimental knowledge of that suggestion. It is our common practice to spray when we are making work that we wish to have as complete as possible, in order to pile up the glaze, but I have never noticed any direct connection between spraying and crawling or not crawling.

Mr. Plusch: With reference to the crawling of glaze on underfired biscuit, last fall I was called in consultation on just such a problem.

The heat to which the biscuit kilns were originally fired in an art pottery was lowered to see if an economy in fuel and time could be effected.

The ware seemed to take the glaze all right whether sprayed, dipped or painted, except where it was applied too thickly when it would crack and fall off in the unfired state. A number of pieces, however, which took the glaze properly showed crawling

on the fired ware. We were led to the conclusion that the softer fired biscuit absorbed more glaze than did the higher fired biscuit previously in use; and that with the thicker layer of glaze, separations, which were not noticeable in the green state, developed thus causing the defect.

The only thing which was done to remedy this defect was to fire the biscuit kiln to a higher temperature.

Mr. Townsend: We find in mat glazes that the greens crawl more than the browns and blues; how would you explain this?

Mr. Binns: I cannot explain it.

Mr. Townsend: Did you use copper in that glaze?

Mr. Binns: There is no copper in this glaze.

Mr. Burt: I have forgotten whether it is Seger, but somebody long ago said that in the application of the glaze, the process, whether correct or not, can be determined nicely; that is, as you apply your glaze, it must be momentarily wet and then gradually dry. If you put your glaze on and the glaze instantly becomes dry, as it would, for instance, if you apply it to a piece of plaster, you are going to have trouble. If, on the other hand, you take a vitrified piece of clay, apply your glaze to it, and that glaze stays wet a length of time, you will have an equivalent trouble. So, when you are working on a varying biscuit, I think the problem resolves itself into an adjustment of your glaze through various mediums, as the addition of gums, to insure a proper drying process. You can easily see if the body is going to momentarily appear wet and then gradually dry out. In other words, you don't want a body too porous, you don't want a body absolutely vitrified.

Mr. Binns: I will call Mr. Burt's attention to the fact that all the pieces were soaked to saturation first; there was no absorption at all when the glaze was applied.

Mr. Parmelee: As you alter the composition of the glaze, to change those factors you must necessarily change the conditions. In the Bristol type of a glaze, of course there is the factor of a breaking glaze surface; the glaze is quite viscous and will not heal the break. With a mat glaze, the viscosity of the glaze undoubtedly affects or retards or prevents the healing of that surface. The influence of the oxides and the influence on viscosity is, I think, the explanation.

THE PROPERTIES OF SOME AMERICAN BOND CLAYS [1]

BY A. V. BLEININGER AND G. A. LOOMIS, PITTSBURGH, PA.

Considerable activity has prevailed during the last two years in searching for domestic refractory clays possessing sufficient plasticity, bonding power, and strength to be used in the manufacture of glass refractories, graphite crucibles, and similar products. The properties of the European clays formerly imported for this purpose have been described in a previous publication.[2] The clay products section of the Bureau of Standards, during the last two years, has come into possession of a number of samples of American plastic bond clays. It was thought advisable to publish the results of tests made upon clays of this type. The tests made consisted in the determination of the water of plasticity, the drying shrinkage (by volume), the apparent specific gravity in the dried state, the rate of slaking, the modulus of rupture of dried bars made from each clay with and without admixture of sand, the porosity and volume changes at different firing temperatures, and the softening points compared with those of the standard pyrometric cones. From the water content and the drying shrinkage, the ratio of pore water to shrinkage water was computed as well as the percentage of shrinkage water in terms of the true clay volume and the total water content.

METHODS OF TESTING

Water of Plasticity. — The entire sample was first ground and screened through the 12-mesh sieve, thoroughly mixed, and a sufficiently large portion removed for all the tests. The clay was made up with water and thoroughly wedged till it had assumed what was considered the best plastic condition. It was then made up into briquettes 2 in. by 1¼ in. by 1 in. and into bars 1 in. by 1 in. by 7 in. The weight of several briquettes was

[1] By permission of the Director, Bureau of Standards.
[2] *Bureau of Standards, Technologic Paper, No. 79.*

determined in the wet state and after complete drying by heating to 110°C. The water of plasticity was taken to be the weight lost in drying, computed in percent of the dry weight.

Drying Shrinkage. — In carrying out this determination the volume of the briquettes was found by immersing them in petroleum immediately after molding and after standing for some hours determining their volume in a volumenometer of the Seger type, provided with a burette, reading to 0.05 cc. After removing the specimens, they were allowed to dry first at atmospheric temperature and then heated to 110° C. The dry specimens were weighed at once, again immersed in petroleum usually for 12 hours or longer, whereupon the volumes were determined as before. From the differences in the volumes of the briquettes in the wet and in the dry state, the shrinkage was computed in terms of the dry volume. From the weights of the dry specimens and their volumes, the apparent specific gravity was readily computed by dividing the volume, expressed in cubic centimeters, into the weight, in grams.

From the wet and dry weights and the wet and dry volumes of the briquettes and the true specific gravity of the clay, it was possible to calculate the volume of the shrinkage and the pore water in terms of the true clay volume. These computations were based on the following obvious relations:

$\frac{100(W_1 - W_2)}{W_2} = a$ = volume of total water in terms of the true clay volume, expressed in percent.

and

$\frac{100(v_1 - v_2)}{W_2} = b$ = volume of shrinkage water, in terms of the true clay substance, expressed in percent.

In these formulae

s = specific gravity of clay, approaching the value 2.60 quite closely for all clays of this type.
w_1 = weight of briquette in the wet state.
w_2 = weight of dry briquette.
v_1 = volume of briquette in wet state.

v_2 = volume of briquette in the dry state.

The value $(a - b)$ represents, similarly, the volume of pore water and the ratio $\frac{a-b}{b}$ the relation of pore to shrinkage water.

By dividing b by a and multiplying by 100 the percentage of shrinkage water in terms of the volume of total water may be computed.

Rate of Slaking. — This was determined by making mixtures of the clays with potters' flint in the proportion of 1:1 and molding 7/8 in. cubes which were dried at atmospheric temperature and finally at 110°C. Upon immersing the cubes in water at room temperature, suspending them in coarse mesh sieve baskets the time of slaking down was observed. The more plastic the clay, the longer was it found to resist this action.

Modulus of Rupture. — The clays in the form of bars 7 in. by 1 in. by 1 in. were dried, then heated to 110°C and upon cooling were broken transversely. From the dimensions of the pieces and the load required to fracture them, the modulus of rupture was computed according to the usual formula. According to the quantity of clay available from 10 to 15 such bars were made and tested. Another series of such test specimens was prepared from the mixture of clay and sand in the proportion of 1:1. The sand corresponded to the following sieve analysis:

Residue on 40 mesh sieve	53.4 percent.
Residue on 60 mesh sieve	35.8 percent.
Residue on 80 mesh sieve	6.9 percent.
Through 80 mesh sieve	3.9 percent.

All of the sand passed the 30 mesh sieve.

The results given are the averages of at least 10 tests in each case.

Burning Behavior of the Clays. — The briquettes after thorough drying were placed in a test kiln fired with natural gas and burned at a rate corresponding to a temperature increase of 20° C. per hour above 800° C. At temperatures beginning with 1050°C. briquettes were drawn and cooled slowly by being put in a pot furnace brought to red heat, or by being

covered with hot sand. When cooled, these specimens were weighed, immersed in water, boiled in a partial vacuum for five hours and again weighed suspended in water, and weighed in air when fully saturated with water. From these data the porosity was calculated from the well known relation:

$$\frac{100\ (w - d)}{w - s}$$

where

w = wet weight, in air, of briquette.
d = dry weight.
s = suspended weight.

The volumes of the briquettes were determined by means of the volumenometer, using kerosene as the displacing liquid. The volume shrinkage or expansion was invariably expressed in terms of the original volume in the dried state.

Both the porosity-temperature and the volume-temperature relations are extremely significant in expressing the burning behavior of the clays. They show at what temperature the state of greatest density (vitrification) is reached, and they also indicate at what point overburning occurs due to the formation of a vesicular structure. The volume relations are particularly useful in pointing out any expansion which may occur due to the above cause or to the effect of the free quartz which may be present. In general, it may be said that the longer the temperature interval between the point of greatest density, (lowest porosity) and the temperature of overburning—and likewise the higher the temperature at which overfiring occurs—the more useful should be the clay as a refractory material.

Clays, which reach the state of maximum density only very gradually, owing to their high content of silica and which never become really vitrified, are also a very useful type, provided they fulfill the other requirements of plastic bond clays. Such materials are particularly valuable for use in glass refractories. For crucibles, gas-tight muffles, etc., the clays burning dense at a comparatively low temperature, but showing no evidence of overfiring up to quite a high temperature, should be most suitable.

Softening Point. — In making this determination, the clays were made up into cones and placed together with Orton pyrometric cones in a pot furnace heated by means of natural gas and compressed air. The softening point was determined by comparing the deformation point of the clay cones with that of the standard cones and was reported in terms of the latter.

RESULTS

The numerical results obtained in these tests are compiled in Tables I, II and III. In analyzing the data thus presented, it might be advisable to consider briefly the types of clay with which we are dealing here and to establish some arbitrary rules which might aid in classifying the materials. It should be realized that such a classification is necessarily of a tentative character. The clays must be considered from two standpoints: viz., their behavior in the raw state and in burning. From the first point of view two criteria might be employed, the transverso strength of the 1:1 clay-sand mixtures and the ratio of pore to shrinkage water. Arbitrarily we might perhaps say that clays showing a modulus of rupture of 325 pounds per sq. in. or more belong to class "A" and those between 225 and 325 pounds to class "B." The ratio of pore to shrinkage water should in no case exceed 1.00 for clays of the "A" type. Further differentation does not seem possible at the present time. For strong, heavy plastic clays, low in free silica, the ratio undoubtedly should not exceed 0.75 but silicous bond clays such as the Gross Almerode, cannot comply with this specification. It might be added that a certain degree of tolerance, say five percent of the values involved should be allowed in differentiating clays as regards their mechanical strength and the porosity-shrinkage ratio.

With reference to the burning behavior, the overfiring temperature and the softening point are the principal criteria. For very severe service, clays of this type should not become decisively vesicular at a temperature below 1425°C. and should not show a softening point below that of cone 31. It is realized that this specification is not fair to certain plastic clays which are valuable for use in connection with graphite crucibles,

especially for brass melting. It seems, however, that even for this purpose the overfiring temperature should not be much below 1400° and the softening temperature not below that of cone 30. Materials below either of these requirements should not be considered as being high-grade bond clays. Attention might be called to the fact that more weight should be placed on the overfiring temperature than upon the softening point. Other conditions being satisfactory, failure of a clay to comply with this requirement within one cone should not result in its rejection. It is also necessary to note carefully the degree or the rate of overfiring. It is evident that small or gradual changes are not necessarily of importance with reference to the deterioration of the material.

Concerning the general burning behavior of the clays, several classes are to be distinguished in regard to the temperature at which they become dense and that at which overfiring takes place. In this connection it should be said that all clays becoming dense at temperatures below 1400°C. should possess a decided range of practically constant porosity. This is especially necessary where the drop in porosity or its equivalent, the rate of shrinkage, is quite rapid. Clays, which upon reaching the state of maximum density, immediately overfire, should be ruled out at once, excepting in those cases where the overfiring begins at 1425°C. or higher. Since these temperatures are already quite high, any overburning at this point is not of serious significance. This is especially true, owing to the fact that in all these bodies a certain degree of solution of the refractory grog occurs which will raise the overfiring limit. At the same time the grog content in itself operates against the formation of a vesicular structure. However, we are here concerned with a comparison of the clays. A material overfiring at a high temperature is certainly to be preferred to one reaching this stage at a lower temperature.

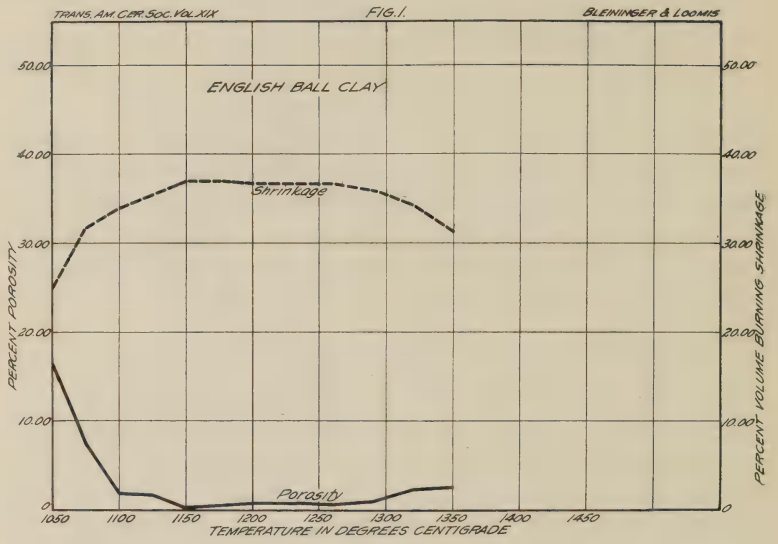
Thus, three classes of useful clays are to be distinguished, First, clays burning dense at about 1150°C. and showing no evidence of overfiring at 1400°C. This class, provided it possesses the other requisite physical properties, is particularly suited for the manufacture of graphite crucibles used in brass melting.

Second, clays burning dense around 1275°C. and not overfiring at 1400°C. or higher. When these clays do not overfire before 1425° they also become valuable for glass refractories. These clays are adapted for crucibles used in steel melting. Third, clays which possess good strength, but do not vitrify at the lower temperatures, becoming dense only at 1425°C. or higher. These clays, overfiring at about 1450° or higher, are particularly useful for the purposes of the glass industries. The unsuitable clays are those which become dense anywhere between 1150° and 1300°, but possess either no range between the temperature of overfiring or only a short one.

DISCUSSION OF THE INDIVIDUAL CLAYS

No. 1, English Ball Clay. — This clay possesses strength to be classed as a bond clay, its modulus being 376 pounds per sq. in. It vitrifies at 1150° and overfires distinctly at 1320° but not seriously. Its porosity and volume changes with temperature are shown in Fig. 1. From the contraction curve, it appears, shown by the downward trend of the curve, that swelling begins at about 1300°. The material, therefore, is not promising for steel melting crucibles and for glass refractories, though it might be satisfactory for brass melting crucibles.

No. 2, Klingenberg, A. T. — The bonding power of this clay is not of an extraordinary quality, and in fact is inferior to that of some American clays. In addition, its tendency to crack badly in drying is an undesirable feature. It has, of course, ample mechanical strength for the purpose it is used for, the making of graphite crucibles. From Fig. 2, it will be seen that it vitrifies at 1125° and remains remarkably constant in structure up to 1425°. At this point overfiring begins as is shown particularly by the volume curve which indicates decided bloating, so that at 1450° the clay has about the same volume it had at 1050° before vitrification took place. At 1450° it is, therefore, decidedly overfired. However, its excellent burning behavior is apparent from the long temperature range. It would not be a satisfactory glass refractory. One disadvantage of this material is its extreme sensitiveness to sudden heating and cooling, as it shatters very


TRANS. AM. CER. SOC. VOL. XIX
FIG. 1.
BLEININGER & LOOMIS
ENGLISH BALL CLAY
Shrinkage
Porosity
PERCENT POROSITY
PERCENT VOLUME BURNING SHRINKAGE
50.00
40.00
30.00
20.00
10.00
0
1050
1100
1150
1200
1250
1300
1350
1400
1450
TEMPERATURE IN DEGREES CENTIGRADE

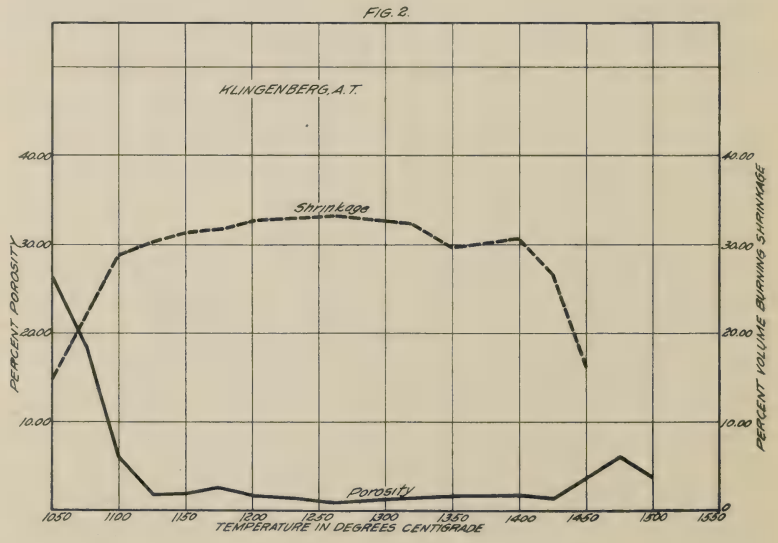


FIG. 2.
KLINGENBERG, A.T.
Shrinkage
Porosity
PERCENT POROSITY
PERCENT VOLUME BURNING SHRINKAGE
40.00
30.00
20.00
10.00
0
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
1550
TEMPERATURE IN DEGREES CENTIGRADE

readily under such conditions. Its softening temperature is satisfactory.

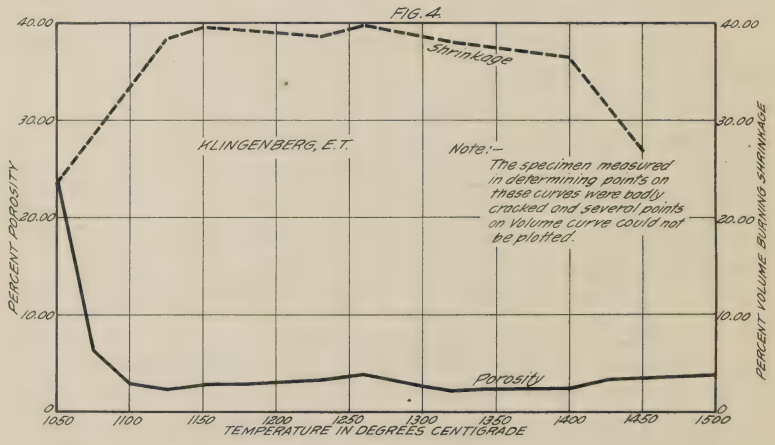
No. 3, New Jersey Clay. — This clay is of a siliceous nature and while it possesses excellent strength in the unmixed state, it is somewhat deficient in bonding power, indicated by its low modulus when admixed with sand, 255 pounds per sq. in. In burning it reaches the vitrified state of 1200° and show evidence of overfiring at 1230° C. It swells decidedly at this temperature. These results together with its low softening point should exclude it from use as a high grade bond clay.

No. 4, Clay from a St. Louis Firm. — This material is an excellent one from the standpoint of plasticity, bonding power, and strength. It shows a modulus of 399 pounds per sq. in. It becomes dense at 1290°, but overfires at 1320°, and at 1350° it has developed a decided vesicular structure indicated both by the volume and porosity changes, as shown in Fig. 3. Its softening point is that of cone 27. The material must, therefore, be rejected as a high grade bond clay.

No. 5, Klingenberg, E. T. — This clay is of a sticky nature and possesses good plasticity and bonding power, its modulus being 363 pounds per sq. in. It has a strong tendency to check and crack in drying. In burning it becomes dense at 1100°, and it shows an extraordinary temperature range up to 1400°. It begins to bloat at this temperature although its porosity is not decidedly increased even at 1450° As is seen from Fig. 4, the volume change is especially useful in indicating the structural changes taking place. It is interesting also to observe the high resistance of the dried clay to the disintegrating action of water.

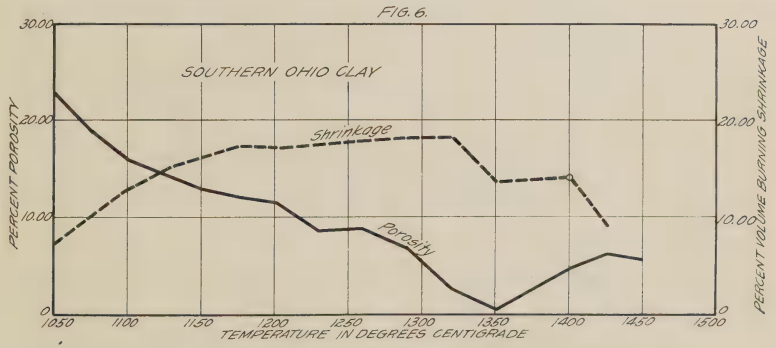
No. 6, Clay from a St. Louis Firm. — This clay is a satisfactory one from the standpoint of its physical properties in the raw state. It shows a modulus of rupture of 351 pounds per sq. in. It becomes quite dense at 1200° and starts to overfire at about 1430°, this condition being distinctly shown at 1450°. It shows thus, an excellent temperature range. Its propensity to bloat at this temperature is quite evident. Its refractoriness is satisfactory, the softening point being equivalent to that of cone 32. The clay seems very promising as a crucible material.

No. 7, Kentucky. — This material is very plastic, but is lacking in bonding power, as indicated by the low modulus, 234 pounds per sq. in. This might be inferred also from the high ratio of pore to shrinkage water, which is 1.05. The specific gravity, 1.55 is below the average of such days. The clay vitri-



fies to a dense structure at about 1260°, remains quite constant up to 1425° when it begins to overfire. At 1450° it shows distinct evidence of this change. (See Fig. 5). Its refractoriness, corresponding to that of cone 32 is satisfactory. This clay could be used in conjunction with a stronger clay as a bonding

material for crucibles but would hardly be suitable for this purpose alone. It might be used also for glass refractories with other clays of somewhat different properties. The high porosity of the clay at 1050°, 37 percent, is indicative of its open



structure in the dried state and explains the ready disintegration of the raw clay in water.

No. 8, Southern Ohio. — This clay, though quite plastic, is somewhat deficient in bonding power. Its modulus with sand is 281 pounds, but its strength without admixture is quite con-

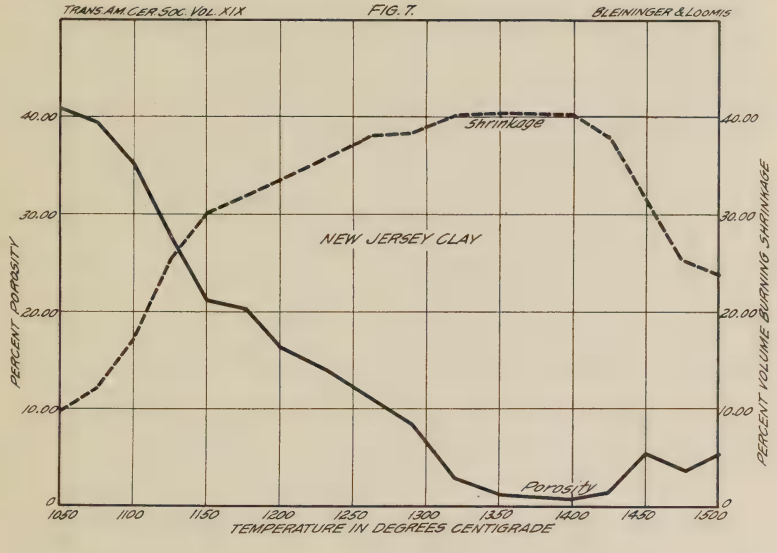
siderable, 479 pounds. Its specific gravity in the dried state is above the average and indicates a dense structure which is verified by its low porosity, 22.83 percent at 1050°. The clay burns to dense vitrification at 1350° and begins to overfire soon after this temperature has been reached. At 1400° it is distinctly vesicular, see Fig. 6. It softens at cone 31. The material is not of the highest type, though it could be used in a mixture with other clays.

No. 9, New Jersey. — The low strength of this clay in the dry state would rule it out from being used as a bond clay by itself. It has, however, good burning qualities which would render it suitable for admixture with one or more strong clays of the dense burning variety. The clay is of a siliceous nature and possesses at 1050° a porosity of 40.80 percent. Its rate of vitrification is gradual and it becomes dense at 1350°. Overfiring starts at about 1425°. Expansion becomes quite evident at this temperature, see Fig. 7. The softening temperature is that of cone 32.

No. 10, English Ball Clay. — This clay, with its satisfactory proportion of shrinkage water to true clay volume 60.8 percent, its pore-shrinkage water ratio of 0.75 and modulus of 389 pounds per sq. in., possesses all the good qualities of a bond clay. This material burns quite dense at 1125° and shows no evidence of overfiring up to about 1415° Overfiring is not serious up to 1450°, see Fig. 8. Its softening point is that of cone 32. This clay should be a useful one for the crucible industry and would be a desirable constituent of a glass pot batch, especially for melting corrosive glasses where a dense pot structure is required.

No. 11, Southern Ohio. — This clay is somewhat similar to sample No. 8.

No. 12, New Jersey. — This clay is of a siliceous character and is lacking in bonding power to such an extent that it would be ruled out from this class. Its firing behavior is that of a siliceous clay, low in fluxes. It becomes very dense at 1475° and begins to overfire beyond this point, see Fig. 9. Its softening point is that of cone 32.


TRANS. AM. CER. SOC. VOL. XIX
FIG. 7.
BLEININGER & LOOMIS
40.00
30.00
20.00
10.00
0
Shrinkage
NEW JERSEY CLAY
Porosity
PERCENT POROSITY
PERCENT VOLUME BURNING SHRINKAGE
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
TEMPERATURE IN DEGREES CENTIGRADE

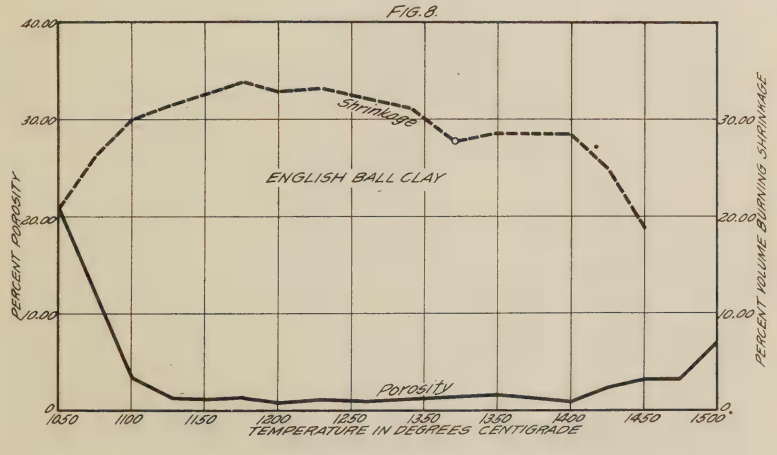
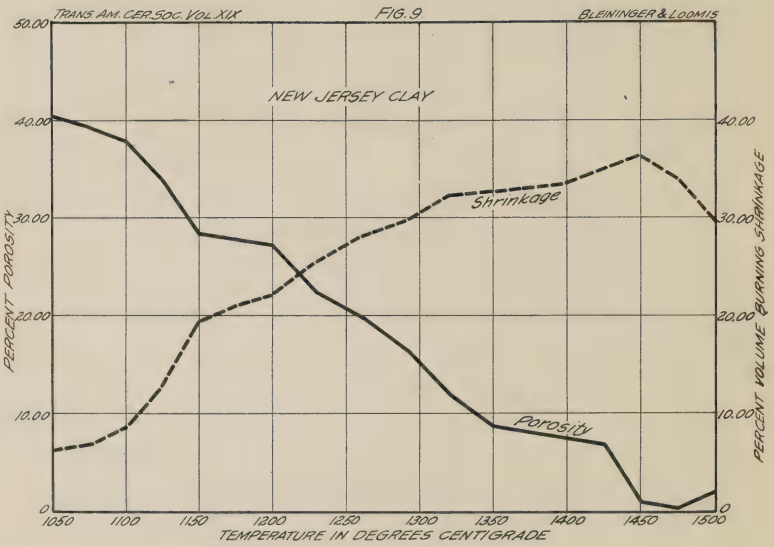


FIG. 8.
40.00
30.00
20.00
10.00
0
Shrinkage
ENGLISH BALL CLAY
Porosity
PERCENT POROSITY
PERCENT VOLUME BURNING SHRINKAGE
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
TEMPERATURE IN DEGREES CENTIGRADE


TRANS. AM. CER. SOC. VOL. XIX
FIG. 9.
BLEININGER & LOOMIS
NEW JERSEY CLAY
Shrinkage
Porosity
PERCENT POROSITY
PERCENT VOLUME BURNING SHRINKAGE
50.00
40.00
30.00
20.00
10.00
0
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
TEMPERATURE IN DEGREES CENTIGRADE

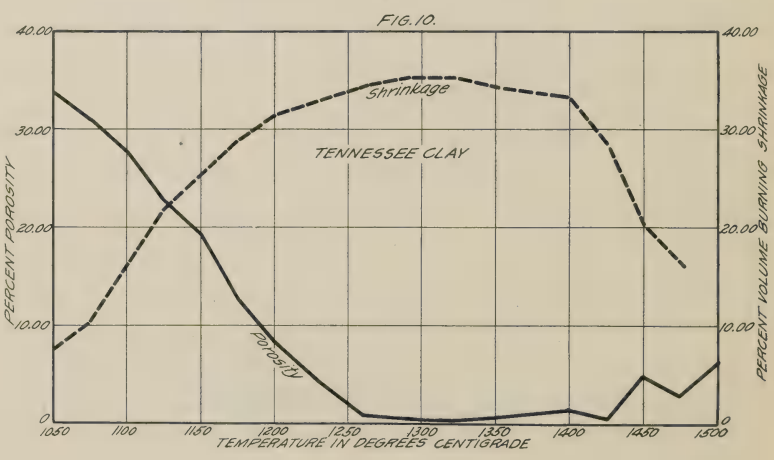
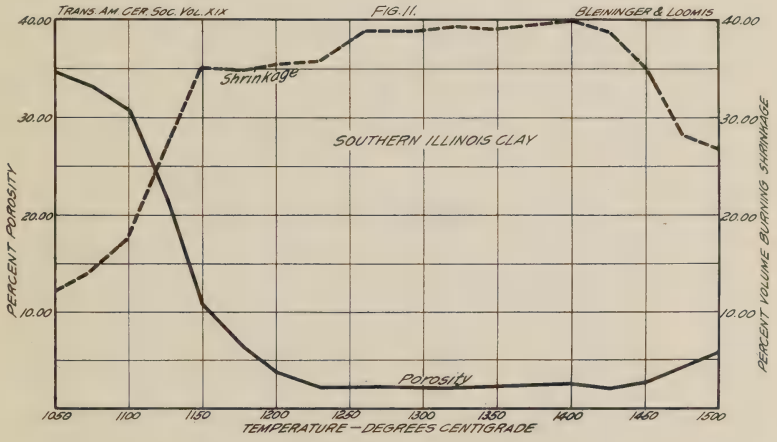


FIG. 10.
Shrinkage
TENNESSEE CLAY
Porosity
PERCENT POROSITY
PERCENT VOLUME BURNING SHRINKAGE
40.00
30.00
20.00
10.00
0
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
TEMPERATURE IN DEGREES CENTIGRADE

No. 13, Tenneesee. — This clay, though of excellent plasticity, is lacking in bonding power as indicated by its modulus of 200 pounds. At 1050° it has a porosity of 33.5 percent and vitrifies gradually, reaching maximum density of structure at about 1260° Practically constant porosity is maintained up to about 1425° when overfiring begins, see Fig. 10. At this point expansion of the clay volume is quite evident. The softening temperature of the material is that of cone 32. In spite of the low bonding power of the clay, it would be useful when admixed with stronger clays owing to its satisfactory firing be-



havior. It would probably be better suited for steel rather than brass melting crucibles.

No. 14, Clay from a St. Louis Firm. — This clay shows remarkable strength and bonding power, its ratio of pore to shrinkage water being 0.54 and its modulus of rupture 554, the highest of all clays tested. At the same time it offers no difficulty in drying, a point in which it is decidedly superior to the Klingenberg clay. It vitrifies completely at 1200°, though it is quite dense at 1175°. The material, however, overfires at 1320° and has a softening temperature of cone 27. The clay, therefore, is not suited for steel melting crucibles or for glass refractories, though it should be useful for brass melting work.

By admixture with one or two more refractory clays it should be possible to improve its firing qualities.

No. 15, Southern Illinois. — This clay possesses excellent plasticity and good bonding power. Its pore-shrinkage water ratio is 0.65 and its modulus 341 pounds. The porosity at 1050° is 34.5 percent, and the clay becomes dense though not completely vitrified at about 1230°. Overfiring does not begin until a temperature of 1450° has been reached. The temperature range of this clay is therefore, a very long one. Overfiring does not take place quickly but evidently is a gradual process, see Fig. 11. The softening point is that of cone 32. The clay is unquestionably one of the best bond clays examined, suitable for both crucible work and glass refractories.

No. 16, Clay from a St. Louis Firm. — This clay possesses good plasticity and bonding power, since its modulus is 351 pounds. In burning, however, it overfires at 1320° and for this reason cannot be considered of particular promise.

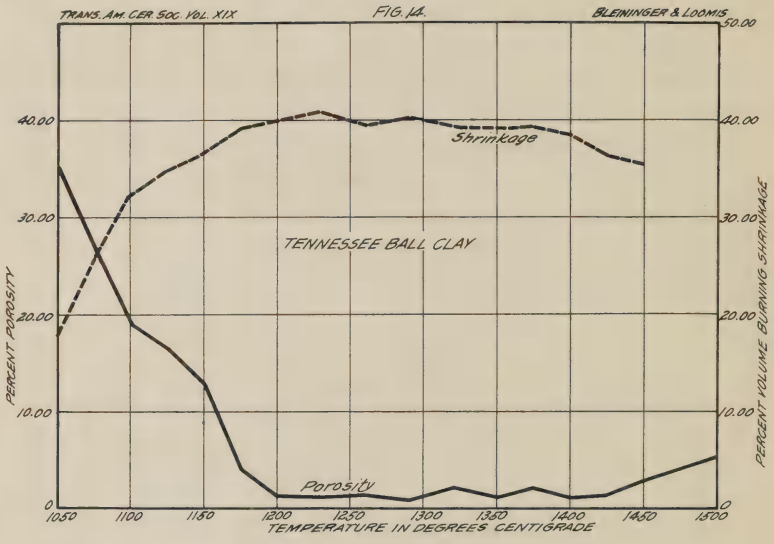
No. 17, Kentucky Ball Clay. — This clay possesses excellent working qualities and good strength. Its shrinkage water content is very high, being 77.4 percent in terms of the true clay volume, its porosity-shrinkage water ratio is 0.71 and its modulus 362. Its porosity at 1050° is 37.8 percent, and it burns to complete vitrification at about 1290°. It begins to overfire at 1400°, but this change is a gradual one. Its softening temperature is that of cone 32. The clay, therefore, is an excellent bond clay, especially suitable for steel melting crucibles and also for glass refractories. Its firing behavior is illustrated graphically in Fig. 12.

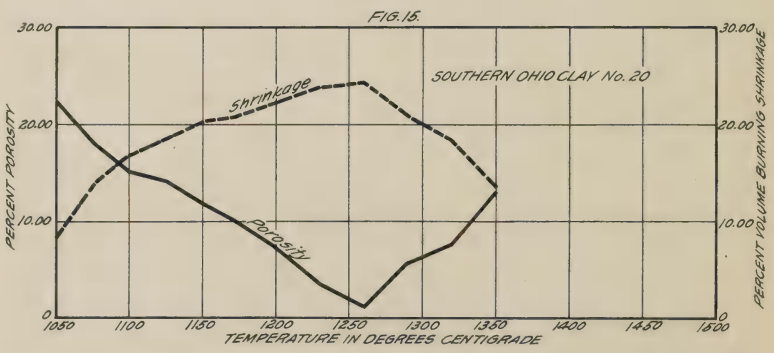
No. 18, Tennessee Ball Clay. — Although this material possesses excellent plasticity, it is somewhat deficient in bonding power as indicated by its high pore-shrinkage water ratio, 0.95 and its low modulus, 228 pounds. On the other hand its firing behavior is excellent. It vitrifies at about 1230° from a porosity of 37.50 percent at 1050°. It remains very constant in structure till 1400° is reached when it begin to overfire very gradually. It still possesses a good structure at 1450°. The softening point corresponds to that of cone 32+. It is undoubtedly a valuable clay chiefly on account of its good firing

TRANS. AM CER SOC. VOL. XIX
FIG. 12.
BLEININGER & LOOMIS
Shrinkage
KENTUCKY BALL CLAY
PERCENT POROSITY
PERCENT VOLUME BURNING SHRINKAGE
40.00
30.00
20.00
10.00
0
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
TEMPERATURE IN DEGREES CENTIGRADE

FIG. 13.
Shrinkage
TENNESSEE BALL CLAY No. 18
Porosity
PERCENT POROSITY
PERCENT VOLUME BURNING SHRINKAGE
40.00
30.00
20.00
10.00
0
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
TEMPERATURE IN DEGREES CENTIGRADE

qualities. It is especially suitable for glass refractories, but for crucible work it requires admixture with a somewhat stronger clay. The firing qualities of this material are illustrated in Fig. 13.

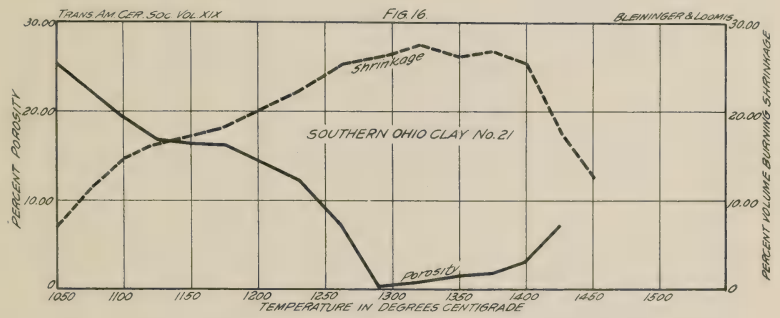


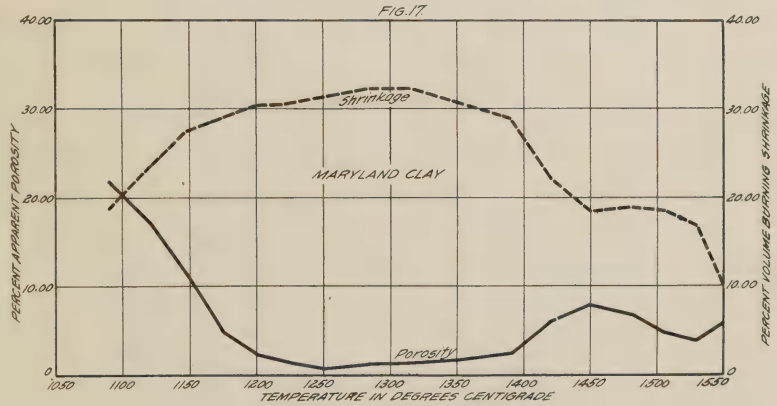


No. 19, Tennessee Ball Clay. — This clay is similar to No. 18. It is, however, decidedly stronger, since its modulus is 282, though it has a smaller shrinkage. It vitrifies at 1200° and does not begin to overfire before 1425°. At 1450° it still shows a

good structure. The overfiring takes place gradually as is seen from Fig. 14. Its softening temperature is about cone 32. What has been said of the previous clay applies also to this material, though it might be said that it is superior to No. 18.

No. 20, Southern Ohio. — This clay is very plastic, and possesses satisfactory bonding power. Its pore-shrinkage water

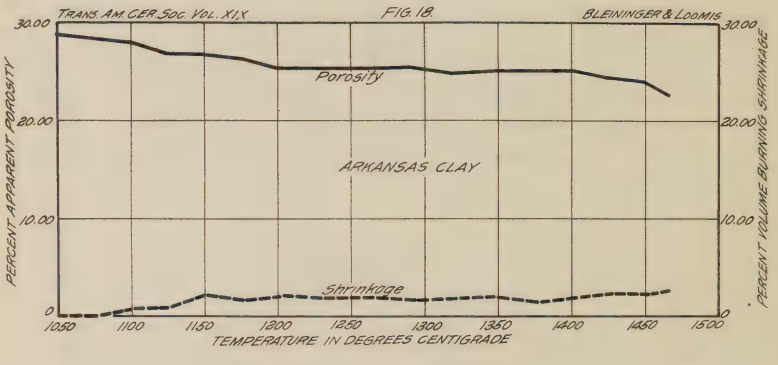


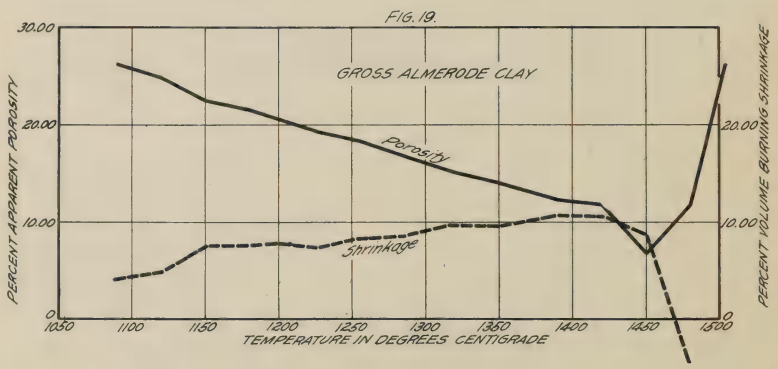


ratio is 0.72 and its modulus 321. Its water content is considerably below the average values holding for the other clays, since it is only 39.7 percent of the true clay volume. For this reason, the density of the molded clay is quite high, the specific gravity being 1.91. The porosity at 1050° is only 22.30 percent, and it vitrifies completely at 1260°, beginning to overfire immediately,

see Fig. 15. The softening point is that of cone $30\frac{1}{2}$. It cannot be considered a bond clay of the highest type in view of these results, and in any event it should not be used alone, but invariably in conjunction with other clays.

No. 21, Southern Ohio. — This clay is similar to No. 20. It is not quite so strong as the former, indicated both by the

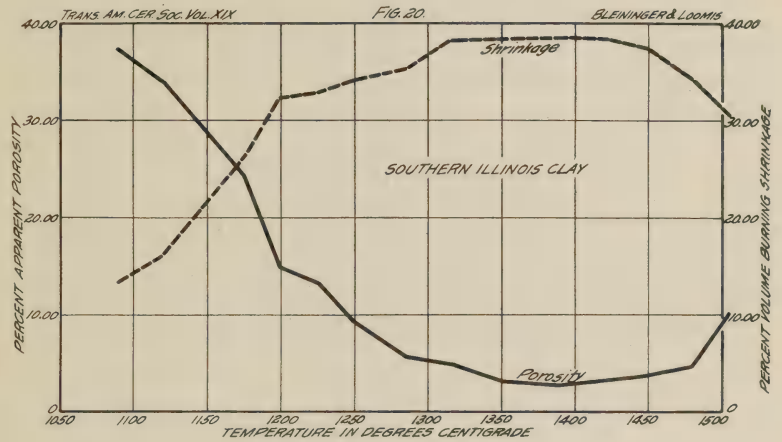


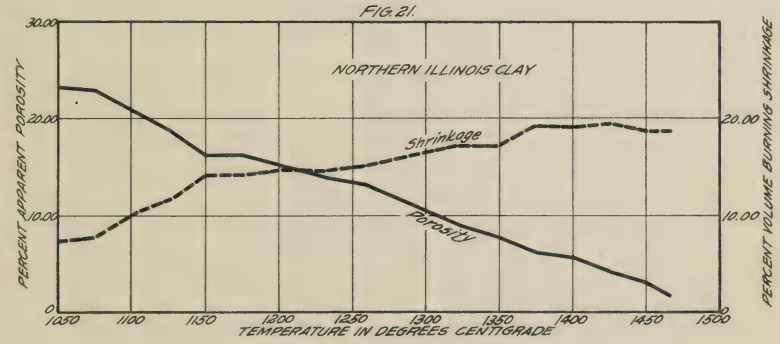


higher pore-shrinkage water ratio, 0.87, and by the lower modulus, 277. It vitrifies more gradually, becoming completely dense at 1290° and overfiring slowly beyond this temperature, see Fig. 16. It is interesting to note that no appreciable volume changes occur until 1400° has been reached, a condition much in favor of the material. For this reason, it is distinctly superior to clay No. 20. It should be useful as part of a bonding

mixture for steel melting crucibles and glass refractories. Its softening temperature is that of cone 31½.

No. 22, Maryland. — In appearances this clay resembles very closely the Klingenberg, A. T. clay. It is black and high in organic matter and exhibits the same charactertistic "stick-





iness." It resists slaking in water still more, though it has a higher pore-shrinkage water ratio. Its total water content is somewhat lower than that of the Klingenberg material. The modulus is 518, which is exceedingly high. Its porosity at 1090° is 21.80 which is greater than that of the Klingenberg at the

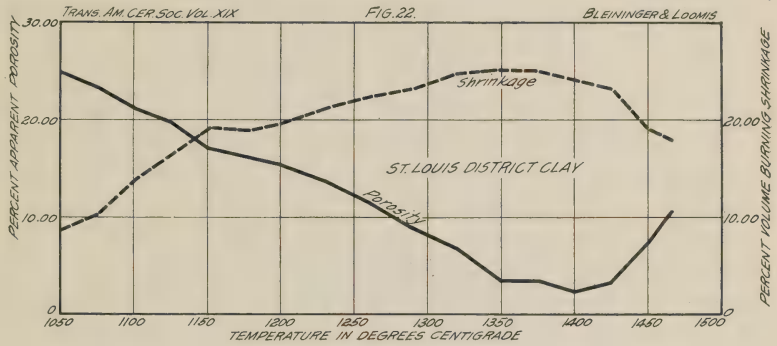
same temperature, and its temperature of complete vitrification is higher, this point being reached at about 1250°. The clay, however, reaches a good dense state at 1200°. Expansion begins to take place somewhat below 1350°, and this change becomes accelerated markedly at 1400°, followed by a stage of quiescence. The material evidently becomes quite viscous at temperatures above 1450°, see Fig. 17. The softening point is that of cone 31. It would seem that this clay should be valuable for the crucible industry, though less suitable for glass refractories.

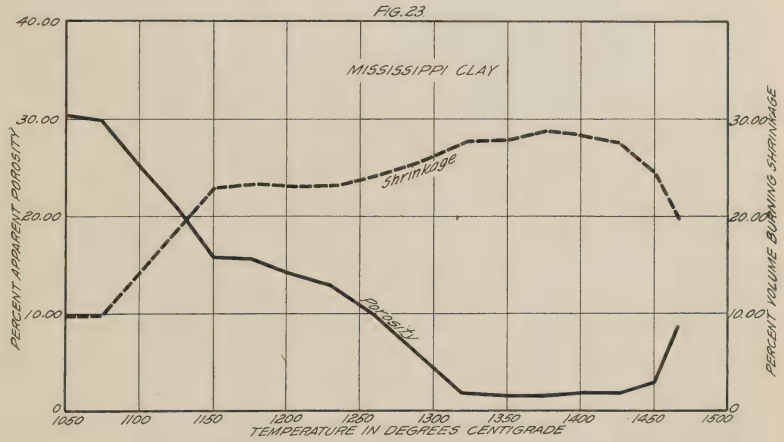
No. 23, Arkansas. — This clay seems to be of the type of the Gross Almerode clay. It is siliceous in character and evidently very low in fluxing materials. It possesses excellent plasticity and bonding power being superior in this respect to the German clay. Its required water content is higher than that of the imported material, amounting to 75.3 percent in terms of the true clay volume. Its pore-shrinkage water ratio also is more favorable, being 0.72. The modulus is 466 pounds. The burning behavior likewise is superior to that of the German clay as may be seen from Fig. 18. It does not vitrify at all within the temperature range employed, its porosity at 1450° being still 23.90 percent. The volume remains remarkably constant. The softening point is that of cone 29. It is evident that this clay is an excellent glass pot material, though not adapted to crucible work, except in connection with another refractory, strong but more dense burning material.

No. 24, Gross Almerode. — This well known clay is very plastic, though its pore-shrinkage water ratio is high, 0.99, characteristic of siliceous clays. Its specific gravity in the dried state is high, it being 1.99. Its bonding power is indicated by the modulus, 364 pounds per sq. in. It burns to a strong, but still somewhat porous structure, 6.95 percent porosity, at 1450° and begins to overfire soon beyond this temperature, see Fig. 19. At this point expansion becomes quite evident. As has been stated before this clay is inferior in its general properties to clay No. 23, its only advantage being that it fires to a denser structure. The same result could be obtained with the Arkansas clay by admixture with a denser firing, but refractory bond

clay, and the result would be more satisfactory. The softening point of this material is that of cone 29.

No. 25, Southern Illinois. — This clay is similar in its characteristics to sample No. 15. Its pore-shrinkage water ratio is not so favorable, 0.75, compared with 0.65, and its modulus is





lower, being 262 pounds per sq. in., though its plasticity is excellent. When fired it shows a somewhat higher porosity, and it does not become quite as dense as No. 15. Its maximum density of structure is not reached before 1350°, while No. 15 becomes dense below 1250°. The clay under consideration is

somewhat more refractory and begins to overfire at a higher temperature, see Fig. 20. Its softening point is that of cone 32 +. In spite of its low bonding power this clay should be very useful as a general refractory bond clay, especially for steel melting crucibles and glass pots. It should be used in connection with somewhat stronger bond clays.

No. 26, Northern Illinois. — This No. 2 fire clay shows the lowest water content of any of these clays. The percent of shrinkage water in terms of the true clay volume is only 27.3 and the pore-shrinkage water ratio is 0.89. This material shows fair plasticity and its modulus is 240. The siliceous character of the clay is indicated by the porosity-temperature diagram, see Fig. 21. It is of the Gross Almerode type and shows a steady progress of vitrification. Overfiring was not yet observed at 1475°. From the burning standpoint the material is a very excellent one. The softening point corresponds to that of cone 29. It is evident that this clay is a useful one, especially when blended with such a material as No. 15. Its primary use would be in connection with glass refractories, though together with a clay like No. 22, it would produce a good crucible mixture, adjusted to produce the desired density of structure at a lower temperature.

No. 27, St. Louis District. — This is a typical clay from this district, of good plasticity, but somewhat deficient in bonding power. The pore-shrinkage water ratio is 0.74 and the modulus 263 pounds per sq. in. Its porosity at 1050° is 25 percent, and vitrification proceeds uniformly and steadily to a porosity of 2.5 percent at 1400°. It does not begin to overfire till 1425°, see Fig. 22. It is, therefore, a very satisfactorily burning material. Here again it should be stated that the best results are obtained in admixture of this clay with a clay of greater bonding power and supplementing its burning characteristics. The softening point is that of cone 31.

No. 28, Mississippi. — This bond clay is of a slightly "sticky" nature, somewhat inclined to crack in drying. Its pore-shrinkage water ratio is 0.81, and its bonding power is very acceptable as indicated by its modulus which is 326 pounds per sq. in. Beginning with a porosity of 30 percent at 1050°

it vitrifies quite gradually becoming dense at 1320°. This condition is maintained constant up to 1450° where overfiring occurs, indicated by expansion on the volume change curve, see Fig. 23. The softening point is that of cone 30. The clay should be generally useful as a bonding material.

SUMMARY

It is hoped that the results here given furnish proof for the assertion that we have in the United States, clays which make possible the manufacture of the several kinds of refractories without the use of imported materials. It is the desire of the writers to emphasize the fact that in nearly every case the use of an intimately blended mixture of suitable clays is to be preferred to the use of single clays. In this manner, using such data as have been here presented, it should be possible to produce bodies possessing all the desired properties. Very similar clays should not be worked together. To illustrate this statement we might say for instance that clay No. 23 (Arkansas) should be blended with clay No. 27 (St. Louis district) for glass refractories. In this manner, by the use of clays which show certain contrasts it should be possible to exercise accurate control over the resulting qualities and hence to secure the best commercial results. A clay like No. 22 (Maryland) should be supplemented by such clays as Nos. 7 (Kentucky), No. 13 (Tennessee), or Nos. 18 and 19 (Tennessee). Again No. 14 would be improved by Nos. 15, 25, or 26 (Illinois). It is evident that in this fashion more or less dense, or again open burning bodies may be produced according to the specific needs of each case. It is very much to be urged that systematic methods of studying these raw materials replace the cut and try procedures which are only too common. For glass refractories a siliceous clay should be used as the basis and reinforced by the addition of suitable dense burning materials.

It goes without saying that there must be many clays of the bond clay type in the United States. In addition, there are available the plastic kaolins, which, though they would not contribute towards the strength of the body are very effective in increasing the refractoriness and raising the overfiring tempera-

TABLE I

(A) LAB. NO.	(B) SOURCE.	(C) WATER IN TERMS OF DRY WEIGHT.	(D) WATER IN TERMS OF TRUE CLAY VOLUME.	(E) SHRINKAGE WATER IN TERMS OF TRUE CLAY VOLUME.	(F) PORE WATER IN TERMS OF TRUE CLAY VOLUME.	(G) RATIO PORE WATER : SHRINKAGE WATER.	(H) SHRINKAGE OF WATER IN TERMS VOLUME OF TOTAL WATER.
		percent	*percent*	*percent*	*percent*		*percent*
1	English ball clay.....	44.90	116.0	64.6	51.4	0.79	50.6
2	Klingenberg, marked A. T.	39.68	104.0	66.4	37.6	0.57	63.8
3	New Jersey	31.23	81.9	48.3	33.6	0.69	58.9
4	From a St. Louis, Mo., firm	31.14	80.7	51.5	29.2	0.57	63.8
5	Klingenberg, marked E. T.	50.66	132.3	84.8	47.5	0.56	64.1
6	From a St. Louis, Mo., firm	43.63	112.0	65.1	46.9	0.72	58.1
7	Kentucky	45.28	117.6	57.2	60.4	1.05	49.6
8	Southern Ohio	22.08	58.2	32.2	26.0	0.80	55.3
9	New Jersey	41.85	108.8	49.4	59.4	1.20	45.4
10	English ball clay.....	40.33	106.5	60.8	45.7	0.75	57.1
11	Southern Ohio	25.30	66.0	35.9	30.1	0.83	54.4
12	New Jersey	34.46	89.7	35.2	54.50	1.54	39.2
13	Tennessee	37.65	98.2	47.8	50.40	1.05	48.6
14	From a St. Louis, Mo., firm	34.66	90.4	58.7	31.7	0.54	62.9
15	Southern Illinois	45.16	117.4	71.0	46.4	0.65	60.4
16	From a St. Louis, Mo., firm	29.54	.....	....	....	....	....
17	Kentucky ball clay....	50.85	132.5	77.4	55.1	0.71	58.4
18	Tennessee ball clay...	46.10	120.0	61.5	58.5	0.95	51.2
19	Tennessee ball clay...	44.73	116.3	58.9	57.4	0.97	50.6
20	Southern Ohio	26.98	68.3	39.7	28.6	0.72	58.1
21	South. Ohio, washed.	26.84	69.5	37.2	32.3	0.87	53.5
22	Maryland	38.91	101.0	60.5	40.5	0.67	59.9
23	Arkansas	29.02	75.3	43.7	31.6	0.72	58.0
24	Gross Almerode	20.64	53.4	26.8	26.6	0.99	50.1
25	Southern Illinois	40.98	106.8	60.9	45.9	0.75	57.0
26	Northern Illinois	19.84	51.6	27.3	24.3	0.89	52.8
27	St. Louis district.....	25.52	66.0	37.8	28.2	0.74	57.2
28	Mississippi	31.39	81.6	45.0	36.6	0.81	55.1

TABLE I.

(I) APPARENT SPECIFIC GRAVITY OF DRIED CLAY.	(J) SHRINKAGE BY VOLUME IN TERMS OF DRY VOLUME.	(K) TIME OF SLAKING.	(L) MODULUS OF RUPTURE OF DRIED CLAY. LBS. PER SQ. IN.	(M) MODULUS OF RUPTURE OF DRIED MIXTURE OF 1 CLAY : 1 SAND. LBS. PER SQ. IN.	(N) REMARKS.
	percent	*minutes*			
1.69	43.30	30	376	323	Inclined to crack in drying.
1.79	42.58	78	345	381	Warps and cracks in drying.
1.90	35.01	12	475	255	No cracking nor warping.
1.94	38.42	52	838	399	No difficulty in drying.
1.70	55.05	108	230	363	Sticky and cracks in drying. Specimens checked.
1.72	43.63	33	328	351	Very fat but dries well.
1.55	34.53	9	239	234	Good plasticity; dries well.
2.01	24.46	8	479	281	Fair plasticity; dries well.
1.56	29.86	20	248	185	Good plasticity, lacking in bonding power; dries well.
1.71	39.85	41	366	389	Strong, plastic, dries well.
1.94	27.92	8½	452	309	Good plasticity; dries well.
1.64	22.12	5½	173	94	Fair plasticity; weak.
1.66	31.01	5½	187	199	Very good plasticity; dries well.
1.90	42.63	117	990	554	Excellent plasticity; dries well.
1.67	45.35	54	439	341	Somewhat "greasy", good plasticity; dries well.
....	37.02	26	575	351	Good plasticity; dries well.
1.57	46.80	36½	359	362	Very plastic, warps, excellent bonding power.
1.59	37.96	18½	326	228	Good plasticity; dries well.
1.56	35.27	27	387	282	Very plastic; warps somewhat.
1.91	29.21	10½	482	321	Very plastic; dries well.
1.88	26.98	10	328	277	Very plastic; dries well.
1.76	40.61	113½	667	518	Sticky, cracks in drying.
1.89	32.32	128	817	466	Very plastic and dries well.
1.99	20.57	49½	502	364	Very plastic; dries well.
1.66	38.81	45	338	262	Somewhat "greasy" but dries well.
2.03	21.08	12	442	240	Fair plasticity; dries well.
1.95	28.52	46	489	263	Good plasticity and dries well.
1.81	31.36	55	645	326	Somewhat sticky and slightly inclined to crack.

TABLE II

NO.	SOURCE	1050° C.		1075° C.		1100° C.		1125° C.	
		POROSITY.	VOLUME SHR'KAGE.	POROSITY.	VOLUME SHR'KAGE.	POROSITY.	VOLUME SHR'KAGE.	POROSITY.	VOLUME SHR'KAGE.
		per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
1	English ball clay.....	16.64	24.80	7.30	35.52	1.99	33.84	1.62	35.30
2	Klingenberg, A. T.....	26.15	14.80	18.62	.....	5.86	28.85	1.74	30.32
3	New Jersey	25.15	11.15	21.85	16.75	16.95	21.00	14.40	22.61
4	From a St. Louis firm.	23.15	6.15	21.81	9.17	17.85	11.50	18.45	12.42
5	Klingenberg, E. T.....	23.92	23.21	6.23	.....	2.90	.....	2.28	38.71
6	From a St. Louis firm.	33.40	14.55	30.80	17.80	22.12	25.52	10.33	32.50
7	Kentucky	37.09	11.49	33.90	16.83	26.02	26.80	21.25	30.90
8	Southern Ohio	22.83	7.34	18.91	10.10	15.82	12.85	14.35	14.87
9	New Jersey	40.80	9.92	39.50	12.24	35.20	17.15	27.75	25.32
10	English ball clay.....	20.70	20.62	11.89	26.28	3.45	30.00	1.49	31.45
11	Southern Ohio	23.55	6.66	21.72	9.97	17.61	11.95	15.01	15.61
12	New Jersey	40.40	6.13	39.20	6.76	37.90	8.68	33.90	12.86
13	Tennessee ball clay....	33.60	7.50	30.80	10.26	27.50	15.71	22.55	21.85
14	From a St. Louis firm.	24.75	7.92	21.95	9.90	18.85	13.05	16.48	15.09
15	Southern Illinois	34.61	12.30	33.20	14.42	30.70	17.70	21.85	27.02
16	From a St. Louis firm.	24.28	.....	15.88	.....	10.57	.....	7.23	.....
17	Kentucky ball clay....	37.80	13.05	30.90	22.70	22.28	30.23	18.25	33.30
18	Tennessee ball clay....	37.50	12.84	28.70	23.45	20.75	31.14	16.95	34.72
19	Tennessee ball clay....	35.48	17.90	26.55	25.60	19.03	32.20	16.50	34.82
20	Southern Ohio	22.30	8.27	18.20	13.62	15.12	16.95	14.08	18.40
21	Southern Ohio, washed.	25.48	7.08	22.43	11.02	19.15	14.50	16.76	16.30
				1090°				1120°	
22	Maryland	.....	.....	21.80	18.22	.....	.....	17.13	23.55
23	Arkansas	28.95	.....	28.50	.....	28.00	0.72	26.92	0.92
						1090°		1120°	
24	Gross Almerode	.....	.....	.....	.....	26.06	4.14	24.92	4.97
						1090°		1120°	
25	Southern Illinois	.....	.....	.....	.....	37.30	13.50	33.90	16.12
26	Northern Illinois	23.12	7.42	22.80	7.78	20.86	10.00	18.95	11.60
27	St. Louis district.....	24.90	8.70	23.35	10.34	21.10	13.62	19.75	16.19
28	Mississippi	30.32	9.75	29.80	9.90	25.30	14.15	20.80	18.62

TABLE II.

1150° C.		1175° C.		1200° C.		1230° C.		1260° C.		1290° C.	
POROSITY.	VOLUME SHR'KAGE.	POROSITY.	VOLUME SHR'KAGE.	POROSITY.	VOLUME SHR'KAGE.	POROSITY.	VOLUME SHR'KAGE.	POROSITY.	VOLUME SHR'KAGE.	POROSITY.	VOLUME SHR'KAGE.
per-cent	*per-cent*	*per-cent*	*per-cent*	*per-cent*	*per-cent*	*per-cent*	*per-cent*	*per-cent*	*per-cent*	*per-cent*	*per-cent*
0.19	36.72	0.31	36.90	0.68	36.63	0.69	36.52	0.50	36.60	0.77	35.91
1.83	31.30	2.50	31.71	1.54	32.65	1.36	.....	0.72	33.18	1.04	.....
9.84	24.90	5.80	26.95	1.83	27.28	2.83	25.05	5.66	19.95	11.01	16.78
15.52	13.18	13.32	13.88	11.95	15.46	9.45	17.82	7.38	19.33	2.66	20.30
2.86	39.50	2.76	.....	.....	.....	3.35	38.60	3.94	39.70	2.96	.....
8.78	33.95	3.95	35.50	1.23	36.45	2.00	37.92	2.44	38.60	1.76	39.30
17.83	34.21	17.05	35.40	12.95	37.01	6.13	39.00	0.19	41.20	0.81	41.75
12.95	16.06	12.02	17.15	11.56	17.10	8.66	17.38	8.71	17.80	6.82	18.06
21.28	30.12	20.35	.....	16.45	33.50	14.09	35.60	11.46	38.08	8.50	38.50
1.28	32.51	1.43	33.80	0.92	32.80	1.11	33.10	0.97	32.05	.....	31.10
12.05	17.95	10.26	18.21	9.71	19.78	6.90	20.83	3.14	21.69	0.49	21.80
28.38	19.30	27.69	20.89	27.10	22.08	22.30	25.40	19.95	28.00	16.56	29.55
19.10	25.35	12.65	28.95	8.13	31.42	4.04	32.70	0.71	34.41	0.34	35.10
11.52	17.25	2.12	18.27	1.02	18.96	1.12	19.56	2.75	18.87	2.82	12.15
10.85	35.15	6.71	34.80	3.85	35.50	2.11	35.85	2.34	38.90	2.02	38.85
4.89	.....	1.91	.....	1.39	.....	1.37	.....	2.29	.....	2.61	.....
16.48	33.25	13.90	34.70	8.43	37.50	3.46	39.02	2.45	40.55	0.98	41.25
13.90	37.10	9.00	36.90	3.77	39.12	.....	40.50	2.29	41.80	1.71	42.75
12.71	36.55	4.05	39.01	1.38	.....	1.07	40.80	1.32	39.50	0.72	40.20
11.82	20.30	9.75	20.95	7.39	22.32	3.58	23.75	1.19	24.20	5.66	20.90
16.38	17.12	16.20	18.25	14.50	20.20	12.22	22.08	7.25	25.12	0.19	26.02
						1225°		1250°		1285°	
10.90	27.52	4.93	29.01	2.14	30.32	1.27	30.55	0.60	31.40	1.17	32.30
26.82	2.13	26.40	1.73	25.45	2.18	25.40	1.92	25.40	1.93	25.60	1.60
						1225°		1250°		1285°	
22.52	7.59	21.70	7.59	20.50	7.84	19.45	7.43	18.69	8.12	16.90	8.55
						1225°		1250°		1285°	
28.89	21.60	24.48	26.40	15.00	32.20	13.27	32.80	9.45	34.05	5.83	35.40
16.37	14.11	16.37	14.16	15.13	14.75	14.05	14.65	13.13	15.35	11.10	16.40
17.05	19.30	16.35	18.76	15.45	19.60	13.72	21.10	11.61	22.30	8.96	23.25
15.96	22.80	15.76	23.30	14.10	23.10	12.92	23.30	9.87	24.20	5.95	25.65

TABLE III

NO	1320° C.		1350° C.		1400° C.		1425° C.		1450° C.
	POROSITY.	VOLUME SHRINKAGE.	POROSITY.	VOLUME SHRINKAGE.	POROSITY.	VOLUME SHRINKAGE.	POROSITY.	VOLUME SHRINKAGE.	POROSITY.
	percent	*percent*	*percent*	*percent*	*percent*	*percent*	*percent*	*percent*	*percent*
1	2.20	34.35	2.31	31.32	.....	.....	.....	.....	.....
2	1.49	32.32	1.56	29.75	1.59	30.70	1.48	26.64	3.93
3	.....	10.83	.....	7.78	.....	.....	.....	.....	.....
4	2.09	19.34	13.75	12.78	.....	.....	.....	.....	.....
5	2.19	38.00	2.47	.....	2.42	36.40	3.23	.....	3.53
6	1.85	38.65	2.08	38.30	2.09	39.55	1.85	38.22	4.61
7	0.97	42.75	0.81	42.60	0.95	42.80	0.33	42.10	3.30
8	2.50	18.18	0.52	13.78	4.56	14.21	6.01	9.08	5.60
9	2.97	40.10	1.16	40.35	0.71	40.25	1.33	37.90	5.45
10	1.38	27.87	1.59	28.65	0.82	28.50	2.34	24.90	3.03
11	0.09	20.65	2.83	16.20	.....	.....	.....	.....	.....
12	11.88	32.15	8.60	.....	.....	33.45	6.68	35.00	0.84
13	0.17	35.10	0.38	34.10	1.28	33.10	0.48	28.50	4.89
14	10.82	8.14	16.90	0.75	.....	.....	.....	.....	.....
15	2.07	39.40	2.27	39.10	2.53	40.00	2.15	38.90	2.72
16	5.62	.....	6.01	.....	.....	.....	.....	.....	.....
17	1.18	41.25	1.48	42.02	0.84	40.80	2.76	39.75	6.00
18	2.34	42.90	1.99	40.95	3.02	39.10	3.22	35.70	4.45
19	2.15	39.30	1.14	39.15	0.82	38.45	1.39	36.10	2.85
20	7.64	18.23	12.95	13.62	.....	.....	.....	.....	.....
21	0.71	27.60	1.46	26.32	3.56	25.41	7.02	17.95	.....
	1315°				1390°		1420°		
22	1.47	32.35	1.53	30.70	2.44	28.85	5.92	22.25	7.95
23	24.95	1.82	25.05	1.81	25.02	1.94	24.40	2.12	23.90
	1315°				1390°		1420°		
24	15.53	9.67	14.10	9.68	12.25	10.70	11.85	10.60	6.95
	1315°				1390°		1420°		
25	5.09	38.12	3.30	38.40	2.86	38.60	3.13	38.40	3.92
26	9.44	17.25	7.98	17.38	5.75	19.23	4.32	19.65	3.08
27	6.93	24.95	3.67	25.20	2.47	24.35	3.48	23.30	7.26
28	1.93	27.55	1.55	27.95	1.81	28.40	1.77	27.65	2.92

TABLE III.

1450° C.	1475° C.		1500° C.		SOFTENING TEMP. IN CONES.	REMARKS.
VOLUME SHRINKAGE.	POROSITY.	VOLUME SHRINKAGE.	POROSITY.	VOLUME SHRINKAGE.		
percent	*percent*	*percent*	*percent*	*percent*		
.....	.....	.....	.....	.....	31½	Overfired at 1320°.
16.35	6.02	.....	3.79	.....	32	Overfired at 1450°. Sensitive to sudden cooling.
.....	.....	.....	.....	.....	27½	Begins to overfire at 1230°.
.....	.....	.....	.....	.....	27	Overfired decidedly at 1350°.
26.85	.....	.....	3.79	.....	32	Cracked in drying and burning. Overfired at 1450°.
34.05	6.54	25.32	7.01	.....	32	Overfired at 1450°.
37.62	4.88	32.90	7.13	.....	32	Overfired at 1450°.
.....	.....	.....	.....	.....	31	Begins to overfire at 1400°.
31.25	3.85	25.30	5.30	23.80	32	Overfired at 1450°.
19.95	3.05	.....	6.95	.....	32	Overfired at 1425°.
.....	.....	.....	.....	.....	30½	Overfired at 1350°.
36.35	0.15	34.00	1.77	29.78	32	Overfired at 1500°.
20.20	2.90	16.28	6.03	.....	32	Overfired at 1425°.
.....	.....	.....	.....	.....	27	Overfired at 1320°.
35.15	4.38	28.35	5.82	26.85	32	Overfired at 1450°.
.....	.....	.....	.....	.....	..	Overfired at 1320°.
37.90	.....	.....	4.85	35.60	32	Overfired at 1450°.
34.50	.....	.....	5.80	33.40	32+	Overfired at 1425°.
35.35	.....	.....	5.18	.....	32+	Overfired at 1450°.
.....	.....	.....	.....	.....	30½	Overfired at 1290°.
12.92	.....	.....	.....	.....	21½	Overfired at 1400°.
	1480°					
18.60	6.95	19.00	4.90	18.65	31	Begins to overfire at 1390°.
2.24	22.55	2.69	.....	.....	29	Does not overfire at 1475°+.
	1480°		1505°			
8.64	11.90	4.73	26.20	11.1	29	Overfired at 1480°.
	1480°		1505°			
37.38	4.54	34.50	10.25	30.80	32+	Overfired at 1475°.
	1470°					
18.85	1.92	18.90	.....	.....	29	Not yet overfired at 1475°.
	1470°					
19.35	10.50	18.10	.....	.....	31	Overfired at 1450°.
	1470°					
24.65	8.63	19.95	.....	.....	30	Begins to overfire at 1450°.

ture. In this laboratory, the use of Georgia and Florida kaolins, in percentage up to 20 percent of the total clay employed, has been found to be very effective for high grade bodies. At the prevailing prices of No. 1 bond clays the use of the unwashed Georgia kaolin would not be prohibitive.

The writers desire to state also that many mistakes have been made in the hurry to develop promising clay properties, some of which would be almost ludicrous if the results were not so serious. These errors consist in including in shipments, entirely unsuitable clays adjoining the strata of good clay, poor judgment in differentiating the different clays, the failure to reject obvious impurities such as pyrites or gypsum and especially in failing to make a comprehensive and thorough survey of the deposits, both by borings and by the sinking of shafts. As a result much disappointment has resulted from developments which were very promising in the beginning but proved disappointing both to the user and the miner. The matter of preliminary clay testing has been practically disregarded entirely excepting by several well established firms, and the cost of experimenting in the use of these clays devolved almost entirely upon the user who in most cases was able to do this only by making up ware — a method of testing which is expensive to say the least. A few easily-made preliminary clay tests would have saved much time, money and disappointment inasmuch as they would have eliminated the most undesirable materials.

DISCUSSION

Mr. Parmelee: I would like to ask Prof. Bleininger whether he can give us some explanation for the fact that there seems to be only a remote connection between the modulus of rupture and the time of slaking? For example, the first clay shows a modulus of rupture of 381 pounds, and the time of disintegration is 78 minutes. In clay No. 15 we have a clay which has a modulus of rupture of 389 pounds, and the time of disintegration is 41 minutes, a difference of only 8 pounds in modulus of rupture, but a difference of 37 minutes in time of slaking.

Mr. Bleininger: I can answer this question only by saying that the organic material obviously exercises a very important

effect and this effect may not be shown so clearly in regard to strength as it is with reference to resistance to disintegration. It seems there is a clogging up of the pores, if I may use that expression. This is shown especially by the Maryland clay, which contains quite a high percentage of highly dispersed organic material.

Mr. Creighton: I would like to ask what criterion is used for over-firing and also the form of testing, whether it is the same form of test piece as used in previous cases.

Mr. Bleininger: Evidence of over-firing is obtained from the porosity-temperature curve and also from the volume-temperature curve. Both are used. In fact, in most cases we use the temperature and volume relations as giving us the first distinct evidence of over-burning. The size of the bars used for the transverse strength test is 7 by 1 by 1 inch.

Mr. Stover: I would like to ask Mr. Bleininger if similar work along the line of kaolins has been done to show the various qualities of the American materials as compared with those which are imported?

Mr. Bleininger: I would like to call Mr. Stover's attention to the work done by Prof. Watts. He has done a very large amount of work along this line.

Mr. Stover: Is that shown in this paper?

Mr. Bleininger: No, Prof. Watts has already published it some years ago. I have no doubt he has additional material.

Mr. Brown: I would like to ask Prof. Bleininger if the clay has a tendency to overburn and overfire, whether it will retain this tendency when introduced into a glass pot or crucible?

Mr. Bleininger: I would like to answer that question by saying, yes. When it comes to temperatures around 1,450 and 1,475, the effect of over-burning will become quite evident in spite of the grog, though the grog has a powerful tendency to minimize this defect by a solution effect. Naturally, the refractory character of the grog and its size of grain are important governing factors. In the present series of tests however we are comparing the clays themselves with each other.

Mr. Purdy: May I ask if we can have, rather definitely, the sources of these clays? In our work, we find that when we

come to make a survey of New Jersey, not knowing just where to go, we do not find the very clays reported in the Transactions or in the Geological Survey reports; definiteness in the location of the clay is lacking.

Mr. Bleininger: Unfortunately we are confronted by certain rules of the Bureau. It would be all right if all clays were of the high grade class, but when we give the exact location of one material and it does not happen to be of the very best grade, that particular owner immediately proceeds to raise objections. Mr. Purdy's question is perfectly justified; I think we ought to do it, and we would like to do it if it were possible. Also unfortunately the question comes up as to exactly where the samples were obtained. Here we are dealing with a weak point; we have no funds or means for going out into the field and selecting the samples ourselves, and consequently we are compelled to take the word of the man who is furnishing the material, as to where he got it, and I might say that in some cases we have difficulty in learning just exactly where the sample came from. The men occasionally seem reluctant to divulge just where the sample was obtained. These are drawbacks, which are very difficult to meet.

Mr. Parmelee: There have been a few remarks made by Prof. Bleininger in regard to the relation of organic matter present in clay. I know that number 17 English ball clay shows a modulus of rupture of 199 pounds and a slaking time of only 6 minutes. Now, in my experience, most of these English ball clays contain a considerable amount of organic matter; is it that that organic matter is in a clearer form, that would explain that?

Mr. Bleininger: Organic matter differs widely in character and covers a multitude of sins. In some cases we are dealing with a very slimy sort of substance which may be entirely lacking in other clays though the amount of organic matter may be the same. I refer again to the Maryland clay, which contains a very peculiar form of organic material, absent in most ball clays.

Mr. Plusch: In answer to Mr. Purdy's question relative to definite locations of different clays, it may be interesting and

valuable for many of us to note that at the Ceramic Department of Rutger's College, at New Brunswick, N. J., there is being compiled a list of clays available in the State of New Jersey. These clays are arranged according to their burning characteristics. They have been fired at several different heats in commercial plants, and an effort is being made, as I understand, to have on hand data as to the miner, location of his mine and so far as possible the quantity of the clay of any particular kind he has available. If a miner runs out of a particular kind of clay and the user wants to duplicate it, he will find these files at Rutger's of extreme value, and I am sure from past experiences that Prof. Brown will be glad to assist our members in locating specific clays available in quantity.

Mr. Brown: Yes, I think the department can give Mr. Purdy any information on these clays, but I believe Mr. Purdy referred to the New Jersey clays which are mentioned in the Transactions.

Mr. Purdy: I was referring to the list before us, not anything which has been given.

NOTE ON THE TEMPERATURE — POROSITY-VOLUME CHANGES OF SOME PORCELAIN BODIES.[1]

BY GEO. A. LOOMIS

The manufacture of chemical and other hard porcelain in this country is being carried on with considerable uncertainty, owing in a great measure, to the fact that the manufacturers are not determining in an accurate manner the burning behavior of the bodies they are using. In one or two instances considerable financial loss has been suffered, due to a lack of information in this respect. For instance, one plant has been using an English ball clay which overburns at cone 12 in a body which was being matured at cone 12, with the result that the ware was being overfired. An accurate study of the burning behavior of this body before being used commercially would have shown this clearly and saved the company from loss.

This brings up the question of how best to make this study. Naturally, the most satisfactory method is that commonly used in the case of single clays; *viz.*, to study the temperature-porosity-volume change curves plotted from data determined, after making a draw trial burn of briquettes molded from the body.

In order to show the advantages of this method of study, as applied to porcelain bodies, several curves showing the burning behavior of some bodies are submitted and will be discussed.

The composition of these bodies is as follows: The clay content of each body is composed of:

	Percent	
Georgia kaolin	10	All washed
North Carolina kaolin	60	
Florida kaolin	30	

[1] By permission of the Director of Bureau of Standards.

BODY NO. 1.

Clay content	50
Feldspar	22
Flint	27
Whiting	1

BODY NO. 2.

Clay content	58
Feldspar	26
Flint	15
Magnesite	1

BODY NO. 3.

Clay content	55
Feldspar	30
Flint	15

BODY NO. 4.

Clay content	55
Feldspar	23
Flint	21
Whiting	1

BODY NO. 5.

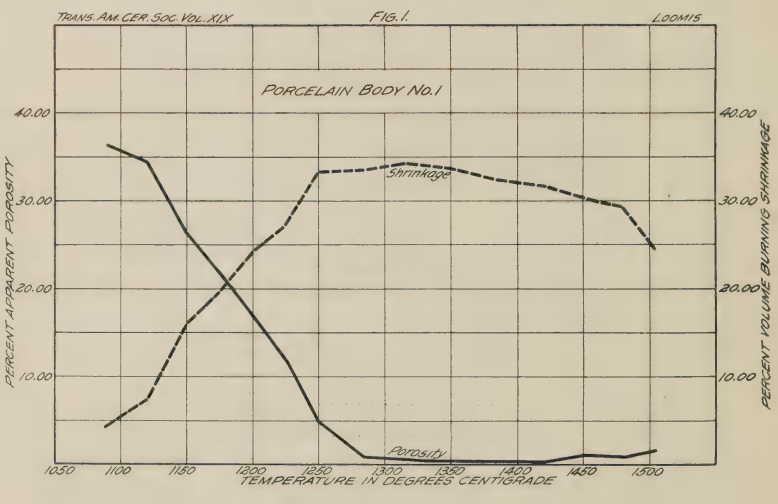
Clay content	55
Feldspar	26
Flint	18
Whiting	1

A draw trial burn was made on briquettes molded from these bodies, firing at the rate of 20° C. per hour from 1000° C. up, in order to approach practical conditions as to rate of firing as nearly as possible. Draws were made every 25° C. between 1100° C. and 1500° C. Porosities were then determined on these briquettes using the usual formula, the wet weights being determined after soaking the specimens in boiling water under vacuum for four hours. The volumes were accurately determined in a

volumeter. These temperature-porosity-volume relations are plotted in Figs. 1, 2, 3, 4, and 5.

From these curves certain deductions can readily be made, noting the maturing temperatures and the temperatures at which the first evidence of overburning takes place. These are compiled in the following table:

BODY NO.	MATURING TEMP. ° C.	BEGINNING OF OVERFIRING ° C.	VITRIFICATION RANGE ° C.
1	1350	1420	70
2	1250	1390	140
3	1317	1417	100
4	1317	1483	166
5	1350	1417	67



Attention is drawn to the fact that body No. 2, having practically the same composition as No. 5, but with 1 percent of magnesite in place of the whiting, matures at 1250°C., while No. 5 does not mature until a temperature of 1350°C. is attained. Then, on the other hand, No. 2 overfires at 1390°C., while No. 5 does not show such behavior up to 1417°C. In like manner an idea is obtained of the permissible temperature range for each body. The criteria of these observations are the porosity relations rather than the volume changes. However, the determina-

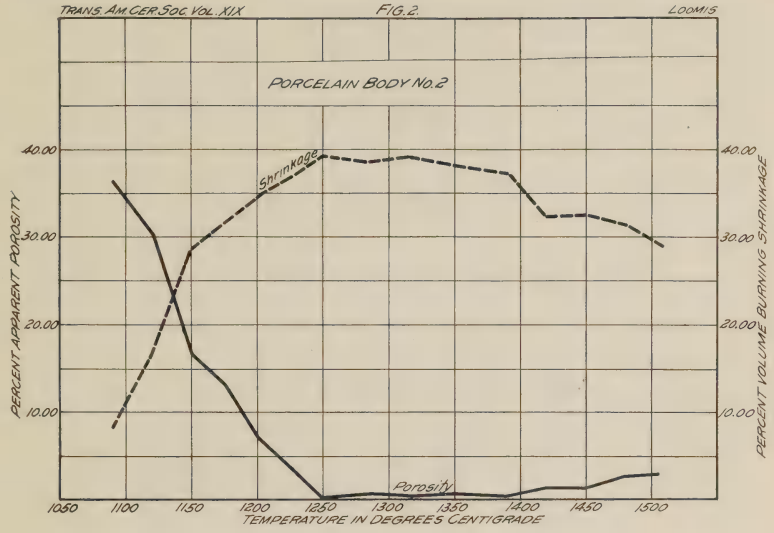
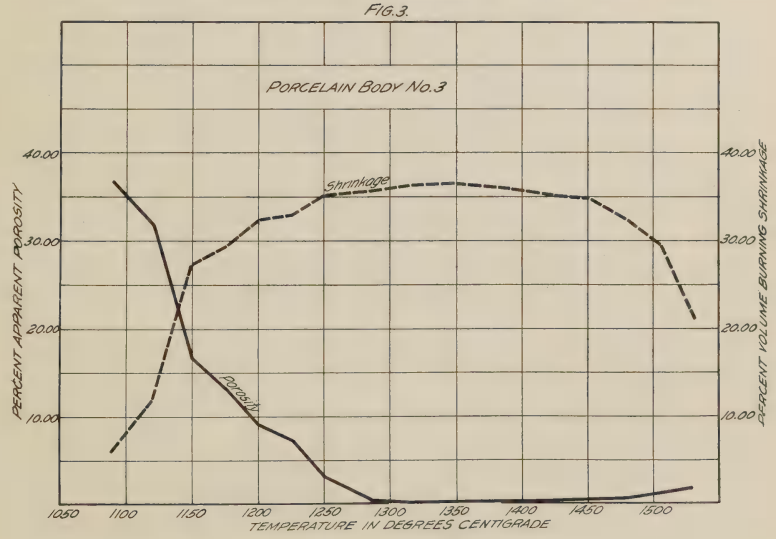
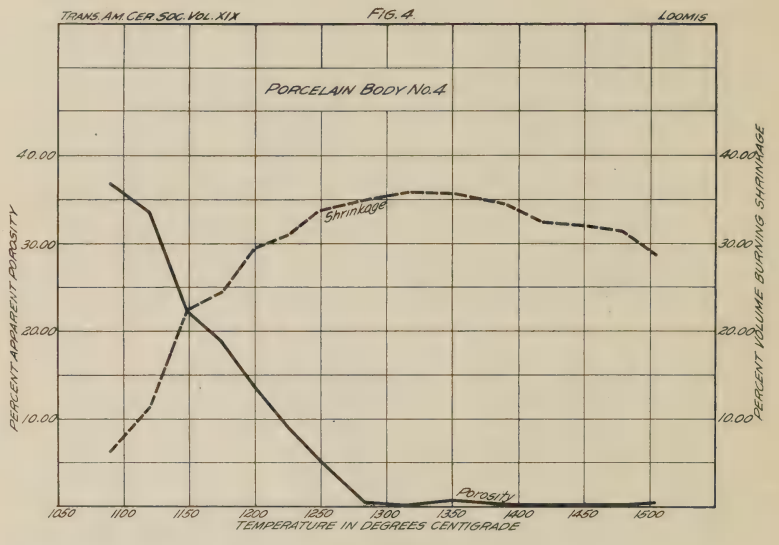

TRANS. AM. CER. SOC. VOL. XIX
FIG. 2.
LOOMIS
PORCELAIN BODY No. 2
Shrinkage
Porosity
40.00
30.00
20.00
10.00
PERCENT APPARENT POROSITY
PERCENT VOLUME BURNING SHRINKAGE
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
TEMPERATURE IN DEGREES CENTIGRADE

FIG. 3.


PORCELAIN BODY No. 3
Shrinkage
Porosity
40.00
30.00
20.00
10.00
PERCENT APPARENT POROSITY
PERCENT VOLUME BURNING SHRINKAGE
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
TEMPERATURE IN DEGREES CENTIGRADE


TRANS. AM. CER. SOC. VOL. XIX
FIG. 4.
LOOMIS
PORCELAIN BODY No. 4
PERCENT APPARENT POROSITY
PERCENT VOLUME BURNING SHRINKAGE
40.00
30.00
20.00
10.00
Shrinkage
Porosity
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
TEMPERATURE IN DEGREES CENTIGRADE

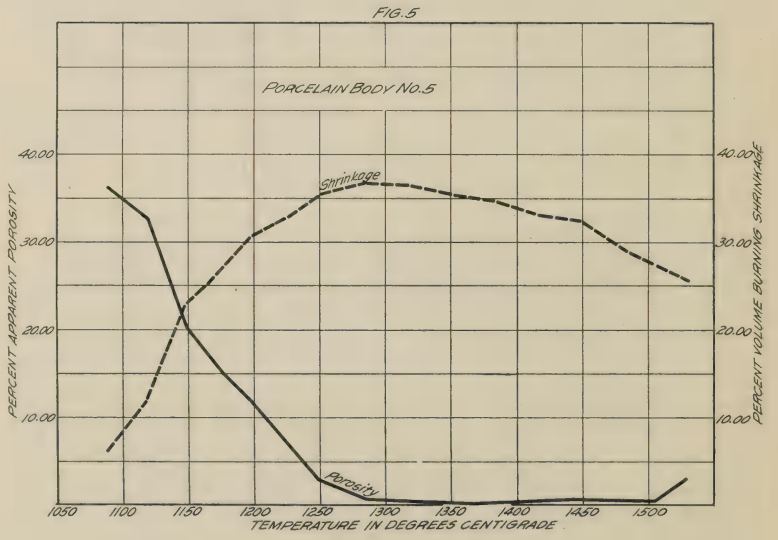


FIG. 5
PORCELAIN BODY No. 5
PERCENT APPARENT POROSITY
PERCENT VOLUME BURNING SHRINKAGE
40.00
30.00
20.00
10.00
Shrinkage
Porosity
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
TEMPERATURE IN DEGREES CENTIGRADE

tion of the latter, as an evidence of overfiring, is much more sensitive than porosity measurements and indicates incipient deterioration of structure considerably earlier. In fact, the volume relation is a little too sensitive a determination of overfiring, except when studied in connection with porosity measurements. However, the body which remains constant in volume during a longer temperature interval, while the porosity remains at a minimum, is certain to be superior to one which exhibits but a short range. Evidently, in the case of the bodies here studied, body No. 1, is the poorest in this respect and Nos. 2 and 3 the best and the latter two would, therefore, prove the safest to burn commercially.

The advantages of making a study of every porcelain body in the manner described, are obvious, and it is extremely important that a general practice of gaining accurate information in this manner be followed, if some of the uncertainties of the porcelain industry are to be overcome.

DISCUSSION

Mr. Minton: I would like to ask Mr. Loomis if it always follows that a clay which would be over-fired at a certain temperature will cause over-firing in the body at that same temperature, regardless of the amount of clay that was used, etc.

Mr. Loomis: There is one talking point for obtaining information in the manner described. Of course we all know that in blending a poor clay with other good clays, the effect of a poor clay is sometimes taken away. By obtaining information in this way, you immediately see whether the effect is re-acted or not.

THE CONTROL OF FUSIBILITY IN FRITTED GLAZES

HOMER F. STALEY AND R. J. RILEY

One objection to the use of ordinary empirical formulæ in glazes for factory work is that they do not provide for the substitution of one chemical for another in such a manner as to keep the maturing temperature of the glaze constant. For instance, we know that if we substitute 0.10 equivalent of CaO for 0.10 equivalent of PbO the glaze will be more refractory. But, if a factory is co-ordinated for a certain glost firing temperature, the manager is not interested in a change of glaze composition that will require a higher fire. What he wants to know is how he can substitute CaO for part of the PbO in his glaze and keep the firing temperature the same.

In working with enamels for metals, one of the authors of this paper evolved a system of empirical physical factors for use in substituting one chemical for another while keeping the fusibility of the enamels the same [1]. This investigation was conducted to see whether a similar system would give satisfactory results in fritted glazes for clay wares.

Series A. As a starting point the following fritted tin enamel was taken: —

Frit:

$$\left.\begin{matrix} 0.231\ K_2O \\ 0.142\ Na_2O \\ 0.094\ CaO \\ 0.521\ PbO \end{matrix}\right\} 0.24\ Al_2O_3 \left\{\begin{matrix} 1.44\ SiO_2 \\ 0.284\ B_2O_3 \\ 0.24\ SnO_2 \end{matrix}\right.$$

Glaze:

1.0 frit	336.73 parts
0.10 clay	25.80 parts
0.60 flint	36.00 parts

[1] *Transactions American Ceramic Society, Vol. XIII, p.* 502.

In this series all substitutions were made in the strong fluxes in the frit. The bulk of the frit was kept constant, but an amount corresponding to 26.4 pounds, melted weight, was taken as the variable. In the original frit, this 26.4 pounds was made up of soda ash, whiting and lead oxide. In each of the others, this 26.4 pounds, melted weight, was supplied as one fluxing oxide. In Table I, are shown the batch weights of the frits, in Table II the percentage composition (calculated) of the melted frits, in Table III the empirical formulæ of the frits. It is not necessary to reduce the glazes to percentage composition or empirical formulæ, but this was done for sake of comparison.

Since the original glaze formula called for 25.8 parts of clay and 26 parts of flint for 336.73 parts of frit, these proportions were used in making a glaze from each of the nine frits. Of course the batch weights and percentage composition of the melted glazes were all the same except for the variable part of the frits. The empirical formulæ varied decidedly, as shown in Table IV.

These glazes were applied to porous white biscuit tile and burned in oil-fired muffle laboratory kilns to cones 05, 02, 1 and 3, with the following results:

Fusibility: As far as could be judged the fusibility of all the glazes was the same.

Texture: With the exception of A5, MgO glaze, all were bright enamels at all temperatures. A5 had a dull luster nearing a semi-mat.

Crazing: None.

Series B. In this series the frits used were the same as those in Series A; but in making up the glazes 54 parts of potash feldspar were used in place of the 36 parts of flint used in the glazes of Series A. In enamels for metals, it has been found that 1½ pounds of potash feldspar has about the same effect on fusibility as 1 pound of flint. As in the case of Series A, the batch weights and the percentage composition of the melted glazes were all the same except for the variable parts of the frits. The empirical formulæ of the glazes are shown in Table V.

TABLE I, SERIES A - BATCH WEIGHTS OF FRITS
FELDSPAR IN FRIT - FLINT IN GLAZE

No.	CONSTANT				VARIABLE - 26.4 POUNDS MELTED							
	Feldspar	Pb_3O_4	Boric acid	Tin oxide	Na_2CO_3	KNO_3	$CaCO_3$	$MgCO_3$	$BaCO_3$	ZnO	Pb_3O_4	$B_2O_3 3H_2O$
1	141.2	114.6	37.2	37.7	15.9		10.0				11.4	
2	141.2	114.6	37.2	37.7	45.5							
3	141.2	114.6	37.2	37.7		56.6						
4	141.2	114.6	37.2	37.7			47.14					
5	141.2	114.6	37.2	37.7				55.0				
6	141.2	114.6	37.2	37.7					32.8			
7	141.2	114.6	37.2	37.7						26.4		
8	141.2	114.6	37.2	37.7							26.9	
9	141.2	114.6	37.2	37.7								48.8

TABLE II, SERIES A - PERCENTAGE COMPOSITION OF MELTED FRITS
FELDSPAR IN FRIT - FLINT IN GLAZE

No.	CONSTANT				VARIABLE							
	Feldspar	PbO	B_2O_3	Tin oxide	Na_2O	K_2O	CaO	MgO	BaO	ZnO	PbO	B_2O_3
1	42.0	33.0	6.0	11.2	2.7		1.7				3.4	
2	42.0	33.0	6.0	11.2	7.7							
3	42.0	33.0	6.0	11.2		7.7						
4	42.0	33.0	6.0	11.2			7.7					
5	42.0	33.0	6.0	11.2				7.7				
6	42.0	33.0	6.0	11.2					7.7			
7	42.0	33.0	6.0	11.2						7.7		
8	42.0	33.0	6.0	11.2							7.7	
9	42.0	33.0	6.0	11.2								7.7

TABLE III, SERIES A - EMPIRICAL FORMULAE OF FRITS
FELDSPAR IN FRIT — FLINT IN GLAZE

No.	K_2O	Na_2O	CaO	MgO	BaO	ZnO	PbO	Al_2O_3	SiO_2	SnO_2	B_2O_3
1	.241	.141	.094				.521	.24	1.4	.23	.28
2	.215	.362					.423	.22	1.20	.21	.25
3	.619						.381	.19	1.16	.16	.19
4	.207		.384				.408	.20	1.25	.20	.24
5	.18			.469			.35	.18	1.08	.17	.21
6	.274				.186		.54	.27	1.64	.27	.32
7	.235					.30	.463	.23	1.41	.23	.27
8	.291						.708	.29	1.74	.28	.34
9	.222						.437	.22	1.37	.22	.601

When these glazes were applied to tile and burned to cones 05, 02, 1 and 3 as in Series A, the following results were obtained: —

Fusibility. The same for all glazes, and very slightly greater than that of glazes in Series A.

Texture. All are dense white, bright enamels except B6, a BaO glaze. B6 is a silky mat at cones 05-02, and a semi-mat at cones 1-3.

Crazing. B3, high K_2O glaze, was crazed at cone 05.

Series C. The frits in this series were the same as those used in Series A and B, except that the feldspar was replaced by flint in the proportion of 1½ pounds of feldspar to 1 pound of flint. The batch weights of the frits are shown in Table VI, the percentage composition (calculated) of the melted frits in Table VII, and the empirical formulæ in Table VIII.

Since in making these frits 94.7 parts of flint were used in place of 142.1 parts of the feldspar in the original frit, the batch weight, melted, of the original frit was reduced to 289.63 parts. Glazes were made from these frits as in Series A by adding 25.8 parts of clay and 36 parts of flint to 289.63 parts of frit. Of course the batch weights and percentage compositions of these glazes differed only in the variable part of the frits. The various glazes differed from the corresponding ones in Series A only in the replacement of feldspar by flint in the frits. The empirical formulæ of the glazes are shown in Table IX.

The results obtained on the sample tiles were as follows: —

Fusibility: C10, C11, C12, C18 are about equal to each other in fusibility and very slightly less than the glazes in Series A. The fusibility of the other glazes could not be judged on account of variation in texture.

Texture: C10, smooth glaze with intermingling of bright and mat texture which gives a beautiful water-marked effect. The distinctness of the marking increases with heat treatment. C11, C12 and C18 are bright enamels. C13, C14 and C15 have stony textures. C16 was a mat at cones 05-02, and a semi-mat at cones 1-3. C17 was a semi-mat at all temperatures.

TABLE IV, SERIES A - EMPIRICAL FORMULAE OF GLAZES
FELDSPAR IN FRIT - FLINT IN GLAZE

No.	No Frit	K_2O	Na_2O	CaO	MgO	BaO	ZnO	PbO	Al_2O_3	SiO_2	SnO_2	B_2O_3
A1	1	.241	.141	.094				.521	.33	2.16	.23	.28
A2	2	.215	.362					.423	.30	1.87	.21	.25
A3	3	.619						.381	.26	1.77	.16	.19
A4	4	.207		.384				.408	.28	1.90	.20	.24
A5	5	.18			.469			.35	.25	1.64	.17	.21
A6	6	.274				.186		.54	.37	2.49	.27	.32
A7	7	.235					.30	.463	.32	2.14	.23	.27
A8	8	.291						.708	.30	2.66	.28	.34
A9	9	.222						.437	.30	2.07	.22	.601

TABLE V, SERIES B - EMPIRICAL FORMULAE OF GLAZES
FELDSPAR IN FRIT - FELDSPAR IN GLAZE

No.	No Frit	K_2O	Na_2O	CaO	MgO	BaO	ZnO	PbO	Al_2O_3	SiO_2	SnO_2	B_2O_3
B1	1	.308	.128	.086				.476	.40	2.00	.21	.25
B2	2	.293	.33					.382	.38	1.80	.19	.22
B3	3	.652						.347	.26	1.75	.14	.17
B4	4	.277		.35				.381	.36	1.90	.18	.22
B5	5	.252			.428			.319	.43	1.60	.16	.20
B6	6	.338				.169		.492	.42	2.21	.24	.29
B7	7	.303					.274	.423	.39	2.00	.21	.24
B8	8	.357						.653	.45	2.31	.26	.31
B9	9	.29						.389	.38	1.86	.23	.591

TABLE VI, SERIES C - BATCH WEIGHT OF FRITS
FLINT IN FRIT - FLINT IN GLAZE

No.	CONSTANT				VARIABLE - 26.4 POUNDS MELTED							
	Pb_3O_4	Flint	Boric acid	Tin oxide	Na_2CO_3	KNO_3	$CaCO_3$	$MgCO_3$	$BaCO_3$	ZnO	Pb_3O_4	$B_2O_3 3H_2O$
10	114.0	94.1	37.2	37.7	15.9		10.0				11.4	
11	114.0	94.1	37.2	37.7	45.5							
12	114.0	94.1	37.2	37.7		56.6						
13	114.0	94.1	37.2	37.7			47.1					
14	114.0	94.1	37.2	37.7				55.0				
15	114.0	94.1	37.2	37.7					33.87			
16	114.0	94.1	37.2	37.7						26.4		
17	114.0	94.1	37.2	37.7							26.9	
18	114.0	94.1	37.2	37.7								48.8

Crazing: C14 is crazed at all temperatures. C16 and C17 at cone 05.

Series D. The same frits were used in this series as in Series C, but in making up the glazes 54 parts of feldspar were used in place of the 36 parts of flint used in the other series. This series is similar to series B except that flint was used in the frits instead of feldspar. The empirical formulæ of the glazes are shown in Table X.

Fusibility: All the glazes are equally fusible at the various cones and slightly more fusible than the good glazes of Series C.

Texture: With the exception of D14, MgO frit, all are bright enamels. D14 is a semi-mat.

Crazing: None.

Series E. In making up the frits for this and the following series, the amount of the variable constitutent was increased by taking half the PbO, 55.7 parts melted, from the constant part of the frit and adding this amount to that to be supplied by a variable. Feldspar was used in all the frits. Thus the frits are similar to those in Series A and B, with the exception that the amount of PbO is less, and the amount of variable is greater. The high MgO frit could not be made to run and so was not used. The high B_2O_3 frit was too soluble to use. Frit 24, high PbO, is a duplicate of frit 8 used in Series A and B. The batch weights of the frits are shown in Table XI, the percentage composition (calculated) of the melted frits in Table XII, and the empirical formulæ of the frits in Table XIII.

Glazes were made up as in Series A, by adding 36 parts of flint and 25.8 parts of clay to 336.63 parts of frit. The empirical formulæ of the glazes are shown in Table XIV.

Fusibility: The various glazes are equally fusible at each heat treatment, the fusibility being about equal to that of Series A.

Texture: E 19 and E 24 are bright enamels at all temperatures. E 20 is semi-mat at cones 02 and bright at cones 1-3. E 21 is immature at cone 05 and a pink silky mat at the other temperatures. E22 is a silky mat at cones 05-02 but a bright

TRANS. AM. CER. SOC. VOL. XIX STALEY & RILEY

TABLE VII, SERIES C – PERCENTAGE COMPOSITION OF MELTED FRITS
FLINT IN FRIT – FLINT IN GLAZE

	CONSTANT				VARIABLE							
No.	PbO	Flint	B_2O_3	Tin oxide	Na_2O	K_2O	CaO	MgO	BaO	ZnO	PbO	B_2O_3
10	37.9	34.6	6.8	12.6	3.1		1.8				3.9	
11	37.9	34.6	6.8	12.6	8.8							
12	37.9	34.6	6.8	12.6		8.8						
13	37.9	34.6	6.8	12.6			8.8					
14	37.9	34.6	6.8	12.6				8.8				
15	37.9	34.6	6.8	12.6					8.8			
16	37.9	34.6	6.8	12.6						8.8		
17	37.9	34.6	6.8	12.6							8.8	
18	37.9	34.6	6.8	12.6								8.8

TABLE VIII, SERIES C – EMPIRICAL FORMULAE OF FRITS
FLINT IN FRIT – FLINT IN GLAZE

No.	K_2O	Na_2O	CaO	MgO	BaO	ZnO	PbO	Al_2O_3	SiO_2	SnO_2	B_2O_3	
10		.187	.125				.688		2.00	.31	.38	
11		.462					.537		1.70	.26	.32	
12	.527						.471		1.47	.23	.28	
13			.484				.515		1.62	.26	.31	
14				.567			.423		1.33	.21	.26	
15					.257		.743		2.41	.37	.44	
16						.393	.606		1.93	.30	.35	
17							1.00		2.63	.40	.48	
18							.55		1.74	.27	.72	

TABLE IX, SERIES C – EMPIRICAL FORMULAE OF GLAZES
FLINT IN FRIT – FLINT IN GLAZE

No.	No Frit	K_2O	Na_2O	CaO	MgO	BaO	ZnO	PbO	Al_2O_3	SiO_2	SnO_2	B_2O_3
C10	10		.187	.125				.688	.125	3.00	.31	.38
C11	11		.462					.537	.107	2.55	.26	.32
C12	12	.527						.471	.094	2.22	.23	.28
C13	13			.484				.515	.103	2.34	.26	.31
C14	14				.567			.423	.086	2.02	.21	.26
C15	15					.257		.743	.15	3.61	.37	.44
C16	16						.393	.606	.12	2.89	.30	.35
C17	17							1.00	.15	3.83	.40	.48
C18	18							.55	.11	2.55	.27	.72

glaze at cones 1-3. E 23 is a bright enamel of low luster which improves with heat treatment.

Crazing: E 19 and E 20 are badly crazed at all temperatures.

TRANS. AM. CER. SOC. VOL. XIX STALEY & RILEY

TABLE X, SERIES D - EMPIRICAL FORMULAE OF GLAZES
FLINT IN FRIT - FELDSPAR IN GLAZE

No.	No Frit	K_2O	Na_2O	CaO	MgO	BaO	ZnO	PbO	Al_2O_3	SiO_2	SnO_2	B_2O_3
D10	10	.088	.170	.114				.627	.18	2.61	.28	.35
D11	11	.088	.421					.489	.18	2.24	.23	.29
D12	12	.569						.429	.18	2.03	.21	.25
D13	13	.088		.441				.469	.18	2.17	.23	.28
D14	14	.088			.516			.385	.18	1.91	.19	.23
D15	15	.088				.234		.677	.18	2.91	.33	.43
D16	16	.088					.358	.552	.18	2.45	.27	.32
D17	17	.088						.911	.18	3.09	.36	.43
D18	18	.088						.501	.18	2.28	.24	.65

TABLE XI, SERIES E - BATCH WEIGHTS OF FRITS
FELDSPAR IN FRIT - FLINT IN GLAZE

No.	Feldspar	Pb_3O_4	Boric acid	Tin oxide	Na_2CO_3	KNO_3	$CaCO_3$	$BaCO_3$	ZnO	Pb_3O_4
19	141.2	56.8	37.3	37.7	141.2					
20	141.2	56.8	37.3	37.7		151.5				
21	141.2	56.8	37.3	37.7			147.4			
22	141.2	56.8	37.3	37.7				105.4		
23	141.2	56.8	37.3	37.7					81.92	
24	141.2	56.8	37.3	37.7						83.7

TABLE XII, SERIES E - PERCENTAGE COMPOSITION OF MELTED FRITS
FELDSPAR IN FRIT - FELDSPAR IN GLAZE

No.	CONSTANT				VARIABLE						
	Feldspar	PbO	B_2O_3	Tin oxide	Na_2O	K_2O	CaO	MgO	BaO	ZnO	PbO
19	41.9	16.3	6.5	11.0	24.3						
20	41.9	16.3	6.5	11.0		24.3					
21	41.9	16.3	6.5	11.0			24.3				
22	41.9	16.3	6.5	11.0					24.3		
23	41.9	16.3	6.5	11.0						24.3	
24	41.9	16.3	6.5	11.0							24.3

Series F. In this series the same frits were used as in Series E. Glazes were made up as in Series B by adding 54 parts of feldspar and 25.8 parts of clay to 336.63 parts of frit. The empirical formulæ of the glazes are shown in Table XV.

Fusibility: The glazes are all of equal fusibility at the various temperatures, and the fusibility is about the same as that of the glazes in Series B, being a little greater than that of Series A and F.

Texture: F 19 and F 24 are bright enamels. F 20 is a semi-mat. F 21 is a pink silky mat at cones 05-02 and semi-mat at

TRANS. AM. CER. SOC. VOL. XIX — STALEY & RILEY

TABLE XIII, SERIES E — EMPIRICAL FORMULAE OF FRITS
FELDSPAR IN FRITS - FLINT IN GLAZE

No	K_2O	Na_2O	CaO	BaO	ZnO	PbO	Al_2O_3	SiO_2	SnO_2	B_2O_3
19	.137	.722				.135	.137	.84	.13	.16
20	.886					.113	.11	.69	.11	.13
21	.129		.745			.127	.13	.77	.13	.15
22	.245			.512		.242	.24	1.47	.24	.29
23	.168				665	.166	.16	1.01	.16	.19
24	.291					.708	.29	1.74	.28	.34

TABLE XIV, SERIES E — EMPIRICAL FORMULAE OF GLAZES
FELDSPAR IN FRITS - FLINT IN GLAZE

No	No Frit	K_2O	Na_2O	CaO	BaO	ZnO	PbO	Al_2O_3	SiO_2	SnO_2	B_2O_3
E 19	19	.137	.722				.135	.191	1.25	.13	.16
E 20	20	.886					.113	.16	1.05	.11	.13
E 21	21	.129		.745			.127	.18	1.17	.13	.15
E 22	22	.245			.512		.242	.33	2.28	.24	.29
E 23	23	.168				.665	.166	.22	1.54	.16	.19
E 24	24	.291					.708	.30	2.66	.28	.34

TABLE XV, SERIES E — EMPIRICAL FORMULAE OF GLAZES
FELDSPAR IN FRIT — FELDSPAR IN GLAZE

No.	No Frit	K_2O	Na_2O	CaO	BaO	ZnO	PbO	Al_2O_3	SiO_2	SnO_2	B_2O_3
F 19	19	.214	.661				.123	.31	1.39	.12	.14
F 20	20	.897					.103	.28	1.34	.10	.12
F 21	21	.207		.678			.115	.30	1.40	.11	.13
F 22	22	.312			.466		.221	.40	2.06	.22	.26
F 23	23	.241				607	.151	.32	1.63	.14	.17
F 24	24	.354					.646	.44	2.30	.25	.31

cones 1-3. E 22 is a silky mat at cones 05-1 and a bright glaze at cone 3. E 23 is a bright glaze of low luster at cone 05 and a silky mat at cones 02-3.

Crazing. E 19 and E 20 at all temperatures.

Factors for Obtaining Melted Weights. Feldspar, flint, tin oxide, zinc oxide, litharge are calculated as not losing any

weight in melting. To get the melted weight of the other chemicals, multiply the raw weight by the factors indicated below.

Red lead	x .974	= PbO
White lead	x .863	= PbO
Barium carbonate	x .78	= BaO
Soda ash	x .58	= Na_2O
Sodium nitrate	x .365	= Na_2O
Magnesium carbonate	x .48	= MgO
Borax	x .53	= Na_2O, $2B_2O_3$
Borax	x .16	= Na_2O
Borax	x .37	= B_2O_3
Pearl ash, calcined	x .68	= K_2O
Potassium nitrate	x .466	= K_2O
Whiting	x .56	= CaO
Boric acid	x .548	= B_2O_3

Factors for Obtaining Raw Weights. We assume that the raw and melted weights are the same for feldspar, flint, tin oxide, zinc oxide, litharge. To get the raw weight from the melted of the others we use the factors indicated below:

PbO	x 1.023	= Red Lead
PbO	x 1.158	= White Lead
BaO	x 1.287	= $BaCO_3$
Na_2O	x 1.724	= Na_2CO_3
Na_2O	x 2.74	= $NaNO_3$
Na_2O from Borax	x 6.25	= Borax
B_2O_3 from Borax	x 2.7	= Borax
Na_2O, B_2O_3 from Borax	x 1.9	= Borax
B_2O_3	x 1.77	= Boric Acid
K_2O	x 1.47	= Pearl Ash
K_2O	x 2.15	= Potassium Nitrate
CaO	x 1.19	= Whiting
MgO	x 2.09	= Mg CO_3

Conclusions. I. The results of this investigation indicate that it is possible to develop a table of the amounts of the

common fluxes and refractories having equal effect on fusibility of fritted glazes.

(a) As a first approximation we may say that for fairly large variations equal melted weights of K_3O, Na_2O, CaO, Mg O, ZnO, PbO, and B_2O_3 have about the same effect on fusibility.[2]

(b) The amounts of flint and feldspar having equal hardening effect must be determined by experiment. In this work we found that 2/3 of a pound of flint had slightly more effect in increasing refractoriness than one pound of feldspar.

II. The extent to which this system of substitution can be employed without affecting the texture of the glazes must be determined by experiment, just as in any other system of calculation.

Incidental to the main investigation we noted as important points in the effect of composition on properties of our fritted enamels the following.

A. High feldspar enamels were better in every way than high flint enamels, being more opaque, of higher luster, and having longer heat ranges.

B. High lime gave enamels that were decidedly pink in color.

---

[2] *Cf. Trans. Amer. Cer. Soc., Vol. XIV,* page 640.

Ceramic Engineering Laboratories,
Iowa State College, Ames.

NOTE ON OVERGLAZE COLORS AT CONE 6-7

BY HEWITT WILSON

This study arose from a problem in yellow and white polychroming on terra cotta. It was necessary to glaze with two colors, twenty-two pilasters and other ornamental features amounting to about five hundred and forty square feet face of terra cotta. The raised ornamental designs consisting of mermaids, flowers, leaves and vases were to be white with a background of yellow. The ornamentation was so varied that one could not use two colored glazes covering one part with paper or plaster pieces while spraying the other color. We have used plaster shields on running courses where two sets of parts would work on all pieces, but even then it is unsatisfactory because the glaze breaks and tears when the plaster shield is removed. Each piece had to be hand touched. We do not know any air brush which is so constructed that dust will not float off and cling to surfaces where it is not wanted, or when it does give a very fine spray, it takes too long to cover any amount of surface with sufficient thickness of glaze so that the color will be uniform and not mottled. The large quantity of ware made the method of separate painting of two colored glazes with a hair brush, too costly. This gives varied shades on large areas due to thick and thin application.

Overglaze Coloring. The method devised consisted of using a white glaze sprayed in the regular way and applying the yellow coloring agents in an overglaze manner to the necessary parts alone. After spraying and when dry, the pieces were transferred to a revolving table, and the yellow overglaze applied with a fine air brush, care being taken to coat the background to an even color and to avoid wetting the raised ornament.

Yellow Overglaze "A"

Roessler and Hasslacher's U.G. NO. 83 or 301 M Yellow Stain.....	68.2	15
Powdered rutile	22.7	5
Uranyl, sulphate or nitrate.....	9.1	2
	100.0	22

The uranyl nitrate has the formula $UO_2(NO_3)_2 \cdot 6H_2O$ M.W. 503.26. It can be interchanged with uranyl sulphate, $UO_2SO_4 \cdot 3H_2O$. M.W. 421.42.

The rutile produces the main body of the color. Alone, it is too strong and dries or wrinkles the glaze in places where applied heavy. It can not be taken into solution by the adjacent glaze surface. The yellow stain is bulky and dilutes the rutile color. It is easily absorbed by the glaze, but when used alone it produces a very faded and varying yellow. It volatilizes in the soaking heat of a large kiln, tho by rapid firing in a small kiln good yellows are produced. The uranium salts being soluble soak into the dry glaze and tie the insoluble parts of the yellow stain and rutile to the white glaze beneath. This soluble part of the overglaze could probably be replaced with a cheaper soluble salt.

Preparation of the Overglaze. After weighing the ingredients, they were ground together in a mortar with 15 cubic centimeters of water per gram of uranium salt. A variation of water causes a variation in the proportion of the soluble salt to the insoluble ingredients. The wet mix is screened thru a three hundred and fifty mesh sieve with a gentle brushing by a camel's hair brush. Forcing the particles thru the screen is bad for the wire mesh and may cause clogging in the delicate air brush.

Before recharging the supply of overglaze in the air brush, the reserve supply is carefully shaken until all sediment is stirred up from the bottom. We found it best to keep a supply in a pint mason jar provided with a lid and rubber ring. The liquid should be screened from time to time and the jar washed to remove dried particles. A few drops of dilute hydrochloric acid

will thin a thickened slip. A small amount of dissolved gum arabic will cause a coagulation which will block the air brush we used. This will require a dissolving of the gum with strong hydrochloric acid.

Cleaning and Firing. The overglaze dries quickly. With the use of a stiff brush the yellow dust is removed from the white raised ornamental figures. The gum arabic in the white glaze hardens the glaze when dry and permits rough brushing in removing the dust. The pieces were set in the usual manner with the other ware in a terra cotta muffle kiln and fired to cone 6-7. Care must be taken to allow no fingers to touch a yellow surface. Very few pieces were marred in this way. However, by respraying the yellow overglaze on the finger marked places and then reburning the blemish is totally removed.

The extra work was that of one man working eighteen days at three dollars per day. The five hundred and forty square feet of terra cotta had fifty-four dollars of extra time plus twelve dollars of material spent upon them, totalling sixty-six dollars and gave each square foot an additional cost of twelve and two-tenths cents.

Air Brush. The fine air brush used in this overglazing was No. D-2-1427 of the Paasche Air Brush Company, Chicago. By proper adjustment, one can either spray a line one-quarter inch in width or cover an area five inches in diameter with spray. However, dust flies in either case, and it must be accounted for. A brush giving a heavier spray than this can not be used with this overglaze as it will wet the raised ornaments with the solution of uranium salts. The insoluble salts can be brushed off leaving an undiscolored white, but if the surface is wet there will be yellow discoloration from the soluble portions of the stain. A larger brush and an overglaze of all insoluble ingredients could be used with alcohol and glycerine as the fluid medium. Or one colored glaze could be used over another, but in this case there is more material to remove from the raised portions, and crow-footing and cracking of some glazes may be caused because of too heavy a coating of the two layers of glaze.

Other Overglaze Colors. Pink, Rose and Tans: Use a common chrome-tin pink satin in place of the yellow overglaze "A" given above. Griffen's[1] pink stain No. 2 is suggested.

Pink Stain No. 2.

Tin oxide	47.0
Whiting	23.5
Potassium dichromate	6.0
Flint	23.5
	100.00

This must not be sprayed very heavy as the high tin content renders solution by the underglaze difficult. To prevent a dusting of the overglaze after the piece is cleaned, spray a thin solution of gum arabic over the surface. This will dry and harden so that the glaze can be roughly handled. However, the base glaze must always have gum arabic in it, as the soaking action produced in spraying the overglaze or the gum solution will cause the base glaze to crack and curl, producing crowfeet during burning.

Good colors are produced by blending the pink and yellow stains. These range from yellows thru tan yellow, yellow tan, light browns, pink browns to pink shades.

Violet: — A violet is produced by blending Griffen's No. 2 pink stain and Griffen's blue No. 1 stain found on page 57.

China clay	40
Zinc oxide	20
Flint	10
Nitrate of soda	10
Oxide of cobalt	20
	100

Use four parts of the pink to one of the blue.

Browns: — In trying to get a green ornament with a yellow background for only a few pieces of terra cotta we used the yel-

[1] *Clay, Glazes and Enamels,* page 54.

low overglaze "A" adjoining a chrome green glaze. The burned yellow background was much browner than usual. Being a good shade of yellow brown we wished to duplicate it. Assuming that the browning was due to chromium fumes, we added green stain No. 14 to the yellow overglaze producing the desired shade with ninety-six parts yellow to four parts green stain. The stain is Stull's[2] green stain No. 14.

No. 14 Green Stain.

Chromium oxide	72.7
Cobalt oxide	0.6
Flint	24.4
Borax	2.3
	100.0

Green: — Most all chromium green glazes burned to cone 6-7 in a large kiln lose their grass green color, and the best development is a yellow green. A good green color was gotten over mat glaze T 13. using a combination of yellow and blue colors.

T. 13.

Flint	13.5
Feldspar	42.0
Whiting	18.9
Zinc oxide	6.1
China clay	9.7
Ball clay	9.8
	100.0

$$\left.\begin{matrix} .222\ K_2O \\ .556\ CaO \\ .222\ ZnO \end{matrix}\right\} .445\ Al_2O_3\ \ 2.44\ SiO_2$$

For green, use two parts Griffen's blue stain No. 1 and one part uranyl nitrate. With each gram of the soluble salt use fifteen cubic centimeters of water. With some glazes the uranium

[2] *Brick and Clay Record*, page 819.

can not balance the blue, and a stronger yellow is needed. In glazes of the type of the above, uranium gives strong yellows ranging into yellow greens when concentrated. Yellow stain "A" having rutile as its base gives browns instead of greens when mixed with blue stains.

The above is but a small number of the innumberable colors and shades which may be developed for this single fire overglaze work. It is possible that these and many other stains could be used over lower-heat glazes at lower temperatures and better and more brilliant colors produced.

Conclusion. This is but a suggestion for the developing of the body, the glaze and the overglaze, all in one burn. Perhaps it should not be called overglazing, which means decorating with colors in a second burn. This is merely adding the coloring oxide to that part of the piece needing it. Akin to this is the painting of soluble metallic salts into parts of an ornamental design requiring the same. Spraying soluble salts gives blurred outlines to a design on account of the side spray which can not be removed from the dry glaze. Pleasing shading and blending effects with the spray of one or more soluble salts are easily obtained.

In underglaze work, during the firing period, the color is either absorbed by the underslip or body, or dissolved in the glaze above. In the overglaze method given above, the coloring matter is incorporated in the upper surface of the glaze but is not dissolved enough to give the same action as if a corresponding percent of stain had been ground and thoroughly mixed with the glaze. In low-heat overglazes, a lower burning glaze is applied over a higher burning one already fired, and the temperature raised, not to the melting point of the base glaze, but only until the overglaze melts and ties into the former. In this case, only the lower surface of the overglaze is affected by the base glaze, and the bulk of it is allowed to retain its individual color. If the temperature is raised until the base glaze starts to melt, the resulting color is the blend of the two glazes — a diluting of the overglaze, and the changes accompanying the pyrochemical union of the ingredients, such as the action of zinc on chromium.

This single fire method for developing both glaze and overglaze is used in producing the old ivory finishes in pottery work.

THE COST OF RAW LEAD GLAZES

BY HOMER F. STALEY AND L. C. HEWITT, AMES, IOWA

A large number of articles dealing with raw lead glazes has been contributed to the Transactions. A partial list of these are given at the end of this article. In this investigation, it was our aim to cover the field of raw lead glazes, by rather large jumps, determine the areas of good bright and mat glazes, and to calculate the cost, for material, of these glazes. To a manufacturer using large quantities of a glaze, it is not enough to know that he has a good glaze. He wishes to know also that this glaze is the cheapest one that can be produced for his purposes.

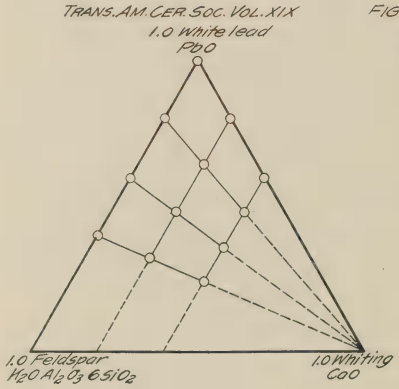
There are five ingredients commonly used in raw lead glazes: feldspar, white lead, whiting, clay, and flint. Our glaze series were constructed of so called "equivalents" and "molecules" of these chemicals. The equivalent weight of white lead used was 258, one-third of the molecular weight and yielding one PbO. Four equivalent ratios of feldspar to PbO; 0:10, 2:8, 4:6, 6:4 were chosen as the basis for the various series. To these two in each of these ratios, whiting was added in such quantity that when the RO of the glaze formula was reduced to unity, the CaO would constitute 0.0, 0.2, or 0.4 of the total RO, the feldspar and PbO, of course, remaining in the same ratio to each other. The twelve combinations of RO bearing minerals thus obtained can be shown either on a triaxial diagram or on a rectangular chart as in Figure I. To each of the twelve combinations, clay was added in amounts of 0.1, 0.2, and 0.3 equivalents, giving 36 glazes. To each of these 36 glazes, flint was added in amounts of 0.5 and 1.0 equivalents, giving an additional 72 glazes.

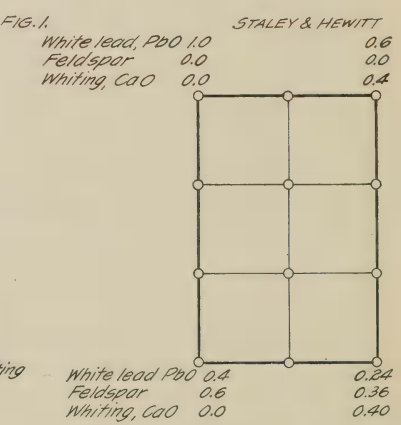
The numbers assigned to the glazes are a key to their equivalent composition. Reading from left to right, the first number indicates the tenths of an equivalent of clay; the second the tenths of an equivalent of whiting (or CaO); the third, the first

half of the equivalent ratio of feldspar to PbO; the fourth, the equivalent amount of flint. Thus number 226.5 is composed of

0.2	clay	
0.2	whiting	
0.48	feldspar	ratio feldspar to PbO 6:4
0.32	white lead	
0.5	flint	

The compositions of the glazes are shown in several forms in Tables I-A to IX-B. In actually compounding the glazes, we made up and ground those that would come on a parallelogram at the four corners of the 0.1 clay, the 0.1 clay 0.5 flint, and the





0.1 clay 0.1 flint series. The corner glazes of the other series were made by adding wet ground clay to these. The intermediate glazes in each series were made by blending the corner ones.

The costs of these glazes are shown in Table X. In computing the costs, the following prices per pound of raw materials were arbitrarily taken:

White lead	$ .07
Feldspar	.005
Whiting	.005
Clay	.005
Flint	.005

TRANS AM CER. SOC VOL. XIX STALEY & HEWITT

TABLE I – COMPOSITION OF GLAZES – SERIES IXX
0.1 EQUIVALENT OF CLAY, NO FLINT

Ratio of Feldspar to PbO	No.	EMPIRICAL FORMULAE					EQUIVALENTS					RAW BATCH				
		K_2O	CaO	PbO	Al_2O_3	SiO_2	Feld-spar	Whit-ing	White lead	Clay	Flint	Feld-spar	Whit-ing	White lead	Clay	Flint
0:10	100	—	—	1.00	0.10	0.20	—	—	1.00	0.10	—	—	—	258	25.8	—
	120	—	0.20	0.80	0.10	0.20	—	0.20	0.80	0.10	—	—	20	206.4	25.8	—
	140	—	0.40	0.60	0.10	0.20	—	0.40	0.60	0.10	—	—	40	154.8	25.8	—
2:8	102	0.20	—	0.80	0.30	1.40	.20	—	0.80	0.10	—	111.4	—	206.4	25.8	—
	122	0.16	0.20	0.64	0.26	1.16	.16	0.20	0.64	0.10	—	89.1	20	165.1	25.8	—
	142	0.12	0.40	0.48	0.22	0.92	.12	0.40	0.48	0.10	—	66.8	40	123.8	25.8	—
4:6	104	0.40	—	0.60	0.50	2.60	.40	—	0.60	0.10	—	222.8	—	154.8	25.8	—
	124	0.32	0.20	0.48	0.42	2.12	.32	0.20	0.48	0.10	—	178.2	20	123.8	25.8	—
	144	0.24	0.40	0.36	0.34	1.64	.24	0.40	0.36	0.10	—	133.7	40	92.9	25.8	—
6:4	106	0.60	—	0.40	0.70	3.80	.60		0.40	0.10	—	334.2	—	103.2	25.8	—
	126	0.48	0.20	0.32	0.58	3.08	.48	0.20	0.32	0.10	—	267.4	20	82.5	25.8	—
	146	0.36	0.40	0.24	0.46	2.36	.36	0.40	0.24	0.10	—	200.5	40	61.9	25.8	—

TABLE II – COMPOSITION OF GLAZES – SERIES 2XX
0.2 EQUIVALENT OF CLAY, NO FLINT

Ratio of Feldspar to PbO	No.	EMPIRICAL FORMULAE					EQUIVALENTS					RAW BATCH				
		K_2O	CaO	PbO	Al_2O_3	SiO_2	Feld-spar	Whit-ing	White lead	Clay	Flint	Feld-spar	Whit-ing	White lead	Clay	Flint
0:10	200	—	—	1.00	0.20	0.40	—	—	1.00	.20	—	—	—	258	51.6	—
	220	—	0.20	0.80	0.20	0.40	—	0.20	0.80	.20	—	—	20	206.4	51.6	—
	240	—	0.40	0.60	0.20	0.40	—	0.40	0.60	.20	—	—	40	154.8	51.6	—
2:8	202	0.20	—	0.80	0.40	1.60	0.20	—	0.80	.20	—	111.4	—	206.4	51.6	—
	222	0.16	0.20	0.64	0.36	1.36	0.16	0.20	0.64	.20	—	89.1	20	165.1	51.6	—
	242	0.12	0.40	0.48	0.32	1.12	0.12	0.40	0.48	.20	—	66.8	40	123.8	51.6	—
4:6	204	0.40	—	0.60	0.60	2.80	0.40	—	0.60	.20	—	222.8	—	154.8	51.6	—
	224	0.32	0.20	0.48	0.52	2.32	0.32	0.20	0.48	.20	—	178.2	20	123.8	51.6	—
	244	0.24	0.40	0.36	0.44	2.84	0.24	0.40	0.36	.20	—	133.7	40	92.9	51.6	—
6:4	206	0.60	—	0.40	0.80	4.00	0.60	—	0.40	.20	—	334.2	—	103.2	51.6	—
	226	0.48	0.20	0.32	0.68	3.28	0.48	0.20	0.32	.20	—	267.4	20	82.5	51.6	—
	246	0.36	0.40	0.24	0.56	2.56	0.36	0.40	0.24	.20	—	200.5	40	61.9	51.6	—

TRANS. AM. CER. SOC. VOL. XIX STALEY & HEWITT

TABLE III - COMPOSITION OF GLAZES - SERIES 3XX
0.3 EQUIVALENT OF CLAY, NO FLINT

Ratio of Feldspar to PbO	No.	EMPIRICAL FORMULAE					EQUIVALENTS					RAW BATCH				
		K_2O	CaO	PbO	Al_2O_3	SiO_2	Feld-spar	Whit-ing	White lead	Clay	Flint	Feld-spar	Whit-ing	White lead	Clay	Flint
0:10	300	—	—	1.00	0.30	0.60	—	—	1.00	0.30	—	—	—	258	77.4	—
	320	—	0.20	0.80	0.30	0.60	—	0.20	0.80	0.30	—	—	20	206.4	77.4	—
	340	—	0.40	0.60	0.30	0.60	—	0.40	0.60	0.30	—	—	40	154.8	77.4	—
2:8	302	0.20	—	0.80	0.50	1.80	0.20	—	0.80	0.30	—	111.4	—	206.4	77.4	—
	322	0.16	0.20	0.64	0.46	1.56	0.16	0.20	0.64	0.30	—	89.1	20	165.1	77.4	—
	342	0.12	0.40	0.48	0.42	1.32	0.12	0.40	0.48	0.30	—	66.8	40	123.8	77.4	—
4:6	304	0.40	—	0.60	0.70	3.00	0.40	—	0.60	0.30	—	222.8	—	154.8	77.4	—
	324	0.32	0.20	0.48	0.62	2.52	0.32	0.20	0.48	0.30	—	178.2	20	123.8	77.4	—
	344	0.24	0.40	0.36	0.54	3.04	0.24	0.40	0.36	0.30	—	133.7	40	92.9	77.4	—
6:4	306	0.60	—	0.40	0.90	4.20	0.60	—	0.40	0.30	—	334.2	—	103.2	77.4	—
	326	0.48	0.20	0.32	0.78	3.48	0.48	0.20	0.32	0.30	—	267.4	20	82.5	77.4	—
	346	0.36	0.40	0.24	0.66	2.76	0.36	0.40	0.24	0.30	—	200.5	40	61.9	77.4	—

TABLE IV - COMPOSITION OF GLAZES - SERIES 1XX.5
0.1 EQUIV. OF CLAY, 0.5 EQUIV. OF FLINT

Ratio of Feldspar to PbO	No.	EMPIRICAL FORMULAE					EQUIVALENTS					RAW BATCH				
		K_2O	CaO	PbO	Al_2O_3	SiO_2	Feld-spar	Whit-ing	White lead	Clay	Flint	Feld-spar	Whit-ing	White lead	Clay	Flint
0:10	100.5	—	—	1.00	0.10	0.70	—	—	1.00	0.10	0.5	—	—	258	25.8	30
	120.5	—	0.20	0.80	0.10	0.70	—	0.20	0.80	0.10	0.5	—	20	206.4	25.8	30
	140.5	—	0.40	0.60	0.10	0.70	—	0.40	0.60	0.10	0.5	—	40	154.8	25.8	30
2:8	102.5	0.20	—	0.80	0.30	1.90	0.20	—	0.80	0.10	0.5	111.4	—	206.4	25.8	30
	122.5	0.16	0.20	0.64	0.26	1.66	0.16	0.20	0.64	0.10	0.5	89.1	20	165.1	25.8	30
	142.5	0.12	0.40	0.48	0.22	1.42	0.12	0.40	0.48	0.10	0.5	66.8	40	123.8	25.8	30
4:6	104.5	0.40	—	0.60	0.50	3.10	0.40	—	0.60	0.10	0.5	222.8	—	154.8	25.8	30
	124.5	0.32	0.20	0.48	0.42	2.62	0.32	0.20	0.48	0.10	0.5	178.2	20	123.8	25.8	30
	144.5	0.24	0.40	0.36	0.34	3.14	0.24	0.40	0.36	0.10	0.5	133.7	40	92.9	25.8	30
6:4	106.5	0.60	—	0.40	0.70	4.30	0.60	—	0.40	0.10	0.5	334.2	—	103.2	25.8	30
	126.5	0.48	0.20	0.32	0.58	3.58	0.48	0.20	0.32	0.10	0.5	267.4	20	82.5	25.8	30
	146.5	0.36	0.40	0.24	0.46	2.86	0.36	0.40	0.24	0.10	0.5	200.5	40	61.9	25.8	30

TRANS. AM. CER. SOC. VOL. XIX STALEY & HEWITT

TABLE V – COMPOSITION OF GLAZES – SERIES 2XX.5
0.2 EQUIV. OF CLAY, 0.5 EQUIV. OF FLINT

Ratio of Feldspar to PbO	No.	EMPIRICAL FORMULAE					EQUIVALENTS					RAW BATCH				
		K_2O	CaO	PbO	Al_2O_3	SiO_2	Feldspar	Whiting	White lead	Clay	Flint	Feldspar	Whiting	White lead	Clay	Flint
0:10	200.5	—	—	1.00	0.20	0.90	—	—	1.00	0.20	0.5	—	—	258	51.6	30
	220.5	—	0.20	0.80	0.20	0.90	—	0.20	0.80	0.20	0.5	—	20	206.4	51.6	30
	240.5	—	0.40	0.60	0.20	0.90	—	0.40	0.60	0.20	0.5	—	40	154.8	51.6	30
2:8	202.5	0.20	—	0.80	0.40	2.10	0.20	—	0.80	0.20	0.5	111.4	—	206.4	51.6	30
	222.5	0.16	0.20	0.64	0.36	1.86	0.16	0.20	0.64	0.20	0.5	89.1	20	165.1	51.6	30
	242.5	0.12	0.40	0.48	0.32	1.52	0.12	0.40	0.48	0.20	0.5	66.8	40	123.8	51.6	30
4:6	204.5	0.40	—	0.60	0.60	3.30	0.40	—	0.60	0.20	0.5	222.8	—	154.8	51.6	30
	224.5	0.32	0.20	0.48	0.52	2.82	0.32	0.20	0.48	0.20	0.5	178.2	20	123.8	51.6	30
	244.5	0.24	0.40	0.36	0.44	3.34	0.24	0.40	0.36	0.20	0.5	133.7	40	92.9	51.6	30
6:4	206.5	0.60	—	0.40	0.80	4.50	0.60	—	0.40	0.20	0.5	334.2	—	103.2	51.6	30
	226.5	0.48	0.20	0.32	0.68	3.48	0.48	0.20	0.32	0.20	0.5	267.4	20	82.5	51.6	30
	246.5	0.36	0.40	0.24	0.56	3.06	0.36	0.40	0.24	0.20	0.5	200.5	40	61.9	51.6	30

TABLE VI – COMPOSITION OF GLAZES – SERIES 3XX.5
0.3 EQUIV. OF CLAY, 0.5 EQUIV. OF FLINT

Ratio of Feldspar to PbO	No.	EMPIRICAL FORMULAE					EQUIVALENTS					RAW BATCH				
		K_2O	CaO	PbO	Al_2O_3	SiO_2	Feldspar	Whiting	White lead	Clay	Flint	Feldspar	Whiting	White lead	Clay	Flint
0:10	300.5	—	—	1.00	0.30	1.10	—	—	1.00	0.30	0.5	—	—	258	77.4	30
	320.5	—	0.20	0.80	0.30	1.10	—	0.20	0.80	0.30	0.5	—	20	206.4	77.4	30
	340.5	—	0.40	0.60	0.30	1.10	—	0.40	0.60	0.30	0.5	—	40	154.8	77.4	30
2:8	302.5	0.20	—	0.80	0.50	2.30	0.20	—	0.80	0.30	0.5	111.4	—	206.4	77.4	30
	322.5	0.16	0.20	0.64	0.46	2.06	0.16	0.20	0.64	0.30	0.5	89.1	20	165.1	77.4	30
	342.5	0.12	0.40	0.48	0.42	2.82	0.12	0.40	0.48	0.30	0.5	66.8	40	123.8	77.4	30
4:6	304.5	0.40	—	0.60	0.70	3.50	0.40	—	0.60	0.30	0.5	222.8	—	154.8	77.4	30
	324.5	0.32	0.20	0.48	0.62	3.02	0.32	0.20	0.48	0.30	0.5	178.2	20	123.8	77.4	30
	344.5	0.24	0.40	0.36	0.54	3.54	0.24	0.40	0.36	0.30	0.5	133.7	40	92.9	77.4	30
6:4	306.5	0.60	—	0.40	0.90	4.70	0.60	—	0.40	0.30	0.5	334.2	—	103.2	77.4	30
	326.5	0.48	0.20	0.32	0.78	3.98	0.48	0.20	0.32	0.30	0.5	267.4	20	82.5	77.4	30
	346.5	0.36	0.40	0.24	0.66	3.26	0.36	0.40	0.24	0.30	0.5	200.5	40	61.9	77.4	30

TRANS. AM. CER. SOC. VOL. XIX STALEY & HEWITT

TABLE VII - COMPOSITION OF GLAZES - SERIES 1XX.1
0.1 EQUIV. OF CLAY, 1.0 EQUIV. OF FLINT

Ratio of Feldspar to PbO	NO.	EMPIRICAL FORMULAE					EQUIVALENTS					RAW BATCH				
		K_2O	CaO	PbO	Al_2O_3	SiO_2	Feld-spar	Whit-ing	White lead	Clay	Flint	Feld-spar	Whit-ing	White lead	Clay	Flint
0:10	1001	—	—	1.00	0.10	1.20	—	—	1.00	0.10	1.0	—	—	258	25.8	60
	1201	—	0.20	0.80	0.10	1.20	—	0.20	0.80	0.10	1.0	—	20	206.4	25.8	60
	1401	—	0.40	0.60	0.10	1.20	—	0.40	0.60	0.10	1.0	—	40	154.8	25.8	60
2:8	1021	0.20	—	0.80	0.30	2.40	0.20	—	0.80	0.10	1.0	111.4	—	206.4	25.8	60
	1221	0.16	0.20	0.64	0.26	2.16	0.16	0.20	0.64	0.10	1.0	89.1	20	165.1	25.8	60
	1421	0.12	0.40	0.48	0.22	1.92	0.12	0.40	0.48	0.10	1.0	66.8	40	123.8	25.8	60
4:6	1041	0.40	—	0.60	0.50	3.60	0.40	—	0.60	0.10	1.0	222.8	—	154.8	25.8	60
	1241	0.32	0.20	0.48	0.42	3.12	0.32	0.20	0.48	0.10	1.0	178.2	20	123.8	25.8	60
	1441	0.24	0.40	0.36	0.34	2.64	0.24	0.40	0.36	0.10	1.0	133.7	40	92.9	25.8	60
6:4	1061	0.60	—	0.40	0.70	4.80	0.60	—	0.40	0.10	1.0	334.2	—	103.2	25.8	60
	1261	0.48	0.20	0.32	0.58	4.08	0.48	0.20	0.32	0.10	1.0	267.4	20	82.5	25.8	60
	1461	0.36	0.40	0.24	0.46	3.36	0.36	0.40	0.24	0.10	1.0	200.5	40	61.9	25.8	60

TABLE VIII - COMPOSITION OF GLAZES - SERIES 2XX.1
0.2 EQUIV. OF CLAY, 1.0 EQUIV. OF FLINT

Ratio of Feldspar to PbO	NO.	EMPIRICAL FORMULAE					EQUIVALENTS					RAW BATCH				
		K_2O	CaO	PbO	Al_2O_3	SiO_2	Feld-spar	Whit-ing	White lead	Clay	Flint	Feld-spar	Whit-ing	White lead	Clay	Flint
0:10	2001	—	—	1.00	0.20	1.40	—	—	1.00	0.20	1.0	—	—	258	51.6	60
	2201	—	0.20	0.80	0.20	1.40	—	0.20	0.80	0.20	1.0	—	20	206.4	51.6	60
	2401	—	0.40	0.60	0.20	1.40	—	0.40	0.60	0.20	1.0	—	40	154.8	51.6	60
2:8	2021	0.20	—	0.80	0.40	2.60	0.20	—	0.80	0.20	1.0	111.4	—	206.4	51.6	60
	2221	0.16	0.20	0.64	0.36	2.36	0.16	0.20	0.64	0.20	1.0	89.1	20	165.1	51.6	60
	2421	0.12	0.40	0.48	0.32	2.12	0.12	0.40	0.48	0.20	1.0	66.8	40	123.8	51.6	60
4:6	2041	0.40	—	0.60	0.60	3.80	0.40	—	0.60	0.20	1.0	222.8	—	154.8	51.6	60
	2241	0.32	0.20	0.48	0.52	3.32	0.32	0.20	0.48	0.20	1.0	178.2	20	123.8	51.6	60
	2441	0.24	0.40	0.36	0.44	3.84	0.24	0.40	0.36	0.20	1.0	133.7	40	92.9	51.6	60
6:4	2061	0.60	—	0.40	0.80	5.00	0.60	—	0.40	0.20	1.0	334.2	—	103.2	51.6	60
	2261	0.48	0.20	0.32	0.68	4.28	0.48	0.20	0.32	0.20	1.0	267.4	20	82.5	51.6	60
	2461	0.36	0.40	0.24	0.56	3.56	0.36	0.40	0.24	0.20	1.0	200.5	40	61.9	51.6	60

Of course the cost of the glazes can easily be recalculated for any other set of costs of materials.

The glazes indicated as Bristol type are not necessarily good stoneware glazes, but are more or less opaque and have a luster corresponding to that of glazes ordinarily used for stoneware. There is a possibility that such glazes might be used in art pottery.

TRANS. AM. CER. SOC. VOL. XIX — STALEY & HEWITT

TABLE IX — COMPOSITION OF GLAZES — SERIES 3XX.1
0.3 EQUIV. OF CLAY, 1.0 EQUIV. OF FLINT

Ratio of Feldspar to RO	No.	EMPIRICAL FORMULAE					EQUIVALENTS					RAW BATCH				
		K_2O	CaO	PbO	Al_2O_3	SiO_2	Feldspar	Whiting	White lead	Clay	Flint	Feldspar	Whiting	White lead	Clay	Flint
0:10	3001	—	—	1.00	0.30	1.60	—	—	1.00	0.30	1.0	—	—	258	77.4	60
	3201	—	0.20	0.80	0.30	1.60	—	0.20	0.80	0.30	1.0	—	20	206.4	77.4	60
	3401	—	0.40	0.60	0.30	1.60	—	0.40	0.60	0.30	1.0	—	40	154.8	77.4	60
2:8	3021	0.20	—	0.80	0.50	2.80	0.20	—	0.80	0.30	1.0	111.4	—	206.4	77.4	60
	3221	0.16	0.20	0.64	0.46	2.56	0.16	0.20	0.64	0.30	1.0	89.1	20	165.1	77.4	60
	3421	0.12	0.40	0.48	0.42	2.32	0.12	0.40	0.48	0.30	1.0	66.8	40	123.8	77.4	60
4:6	3041	0.40	—	0.60	0.70	4.00	0.40	—	0.60	0.30	1.0	222.8	—	154.8	77.4	60
	3241	0.32	0.20	0.48	0.62	3.52	0.32	0.20	0.48	0.30	1.0	178.2	20	123.8	77.4	60
	3441	0.24	0.40	0.36	0.54	4.04	0.24	0.40	0.36	0.30	1.0	133.7	40	92.9	77.4	60
6:4	3061	0.60	—	0.40	0.90	5.20	0.60	—	0.40	0.30	1.0	334.2	—	103.2	77.4	60
	3261	0.48	0.20	0.32	0.78	4.48	0.48	0.20	0.32	0.30	1.0	267.4	20	82.5	77.4	60
	3461	0.36	0.40	0.24	0.66	3.76	0.36	0.40	0.24	0.30	1.0	200.5	40	61.9	77.4	60

In each of the areas plotted all of the glazes were not equally mature, or of equally desirable texture and luster. The plotting simply indicated that these glazes fell into one of the classes indicated. In many cases it was found that a glaze would be mature enough at a low temperature to be considered a good mat or Bristol type, but as the temperature was raised it would turn into a slightly immature bright glaze containing a considerable amount of pinholes and bubbles.

Following is a general summary only of the effect on texture of variation of composition and temperature:

TRANS. AM. CER. SOC. VOL. XIX STALEY & HEWITT

TABLE X - COST OF GLAZES

No	Cost Per Lb. Raw	Cost Per Lb. Melted	No.	Cost Per Lb. Raw	Cost Per Lb. Melted	No.	Cost Per Lb. Raw	Cost Per Lb. Melted
100	$.064	$.074	200	$.057	$.068	300	$.055	$.063
120	.058	.069	220	.053	.066	320	.049	.058
140	.050	.062	240	.045	.056	340	.041	.051
102	.044	.048	202	.041	.045	302	.038	.042
122	.040	.045	222	.037	.042	322	.035	.040
142	.036	.042	242	.033	.039	342	.031	.036
104	.029	.031	204	.028	.030	304	.027	.029
124	.028	.030	224	.026	.028	324	.025	.027
144	.025	.029	244	.023	.027	344	.022	.025
106	.019	.020	206	.018	.019	306	.018	.019
126	.018	.019	226	.017	.018	326	.017	.018
146	.017	.018	246	.016	.018	346	.015	.017
100.5	.058	.066	200.5	.054	.062	300.5	.051	.058
120.5	.052	.061	220.5	.048	.056	320.5	.045	.052
140.5	.045	.056	240.5	.041	.049	340.5	.038	.045
102.5	.040	.044	202.5	.038	.042	302.5	.036	.039
122.5	.037	.041	222.5	.035	.039	322.5	.033	.037
142.5	.033	.038	242.5	.030	.035	342.5	.028	.033
104.5	.028	.030	204.5	.027	.028	304.5	.025	.027
124.5	.026	.028	224.5	.025	.027	324.5	.023	.025
144.5	.023	.026	244.5	.021	.024	344.5	.020	.023
106.5	.018	.019	206.5	.017	.018	306.5	.017	.018
126.5	.017	.018	226.5	.016	.018	326.5	.016	.017
146.5	.016	.017	246.5	.015	.016	346.5	.014	.016
1001	.053	.060	2001	.050	.057	3001	.047	.053
1201	.047	.055	2201	.045	.051	3201	.042	.048
1401	.040	.048	2401	.038	.044	3401	.035	.041
1021	.038	.041	2021	.036	.039	3021	.034	.037
1221	.035	.038	2221	.033	.036	3221	.031	.034
1421	.030	.034	2421	.028	.032	3421	.026	.030
1041	.026	.028	2041	.025	.027	3041	.024	.026
1241	.024	.026	2241	.023	.025	3241	.022	.024
1441	.022	.024	2441	.020	.023	3441	.019	.022
1061	.017	.018	2061	.017	.018	3061	.016	.017
1261	.016	.017	2261	.016	.017	3261	.015	.016
1461	.015	.016	2461	.014	.016	3461	.014	.015

Variation of Lead Oxide-Feldspar. Replacement of lead oxide by feldspar in equal molecular amounts had no decided tendency to change the texture of the glazes. However it does tend to make the glazes more refractory. Thus in making this variation, in a few cases we went from bright glazes to semi-mats in which the dull texture was plainly due to the immaturity of the glaze, since these glazes became bright when the heat treatment was slightly increased.

Variation of CaO. When we increased calcium oxide in the RO, keeping the remaining lead oxide and feldspar in the same ratio to each other, the glazes became more refractory and tended to become semi-mat, then mat.

Variation of Clay. Increase of clay, keeping the rest of the glaze uniform, made the glaze more refractory and tended to increase dull texture.

Variation of Flint. Increase of flint made the glazes more fusible and tended to produce brighter gloss. Exception to this is found in glaze 240 which contained no flint and 240.5 which contained 0.5 eq. flint. The texture of 240 was mostly dull mat, but there were little rivulets of bright surface all thru it. Therefore, we classified it as a semi-mat. The texture of 240.5 was that of a typical silky mat.

Variation in Temperature. Increase of temperature tended to increase the area of bright glazes, centering around the high lead corner of the plots, and to push the area of immature and dull finish glazes further away from this corner.

The bright glazes that had good luster and were free from pin holes are shown in Tables XI and XII. It is to be noted that every one of these contained some flint, the few that were good with 0.5 equivalents being satisfactory also with 1.0 equivalents. The limit of the amount of flint that could be added to some of the glazes in this investigation was not reached. None of the glazes containing feldspar were good bright glazes below cone 3. The jump from no feldspar to 0.2 equivalents is a large one, and further study should be made of the effect of smaller amounts of feldspar. In fact, we know that 0.1 equivalent of feldspar can be used in bright glazes at cone 05. Two-tenths equivalents of Ca O was present in some of the glazes at cones

TABLE XI – GOOD BRIGHT GLAZES

No.	BATCH EQUIVALENTS					EMPERICAL FORMULAE				
	Feld-spar	Whit-ing	White lead	Clay	Flint	K_2O	CaO	PbO	Al_2O_3	SiO_2
100.5			1.00	0.10	0.50			1.00	0.10	0.70
120.5		0.20	0.80	0.10	0.50		0.20	0.80	0.10	0.70
200.5			1.00	0.20	0.50			1.00	0.20	0.90
1001			1.00	0.10	1.00			1.00	0.10	1.20
1021	0.20		0.80	0.10	1.00	0.20		0.80	0.30	2.40
1201		0.20	0.80	0.10	1.00		0.20	0.80	0.10	1.20
1221	0.16	0.20	0.64	0.10	1.00	0.16	0.20	0.64	0.26	2.16
2001			1.00	0.20	1.00			1.00	0.20	1.40
2021	0.20		0.80	0.20	1.00	0.20		0.80	0.40	2.60
2201		0.20	0.80	0.20	1.00		0.20	0.80	0.20	1.40
2221	0.16	0.20	0.64	0.20	1.00	0.16	0.20	0.64	0.36	2.36
2401		0.40	0.60	0.20	1.00		0.40	0.60	0.20	1.40
2421	0.12	0.40	0.48	0.20	1.00	0.12	0.40	0.48	0.32	2.12
3001			1.00	0.30	1.00			1.00	0.30	1.60

TABLE XII – GOOD BRIGHT GLAZES

No.	Oxygen Ratio	TEXTURE AT CONE				COST PER LB.	
		05	02	1	3	Raw	Melted
100.5	1 : 1.07	B.	B.	B.	B.	$.058	$.066
120.5	1 : 1.07	B.	B.	B.	B.	.052	.061
200.5	1 : 1.12	B.	B.F.	B.F.	B.F	.054	.062
1001	1 : 1.84	B.	B.	B.	B.	.053	.060
1021	1 : 2.52	B.I.	B.P.	B.P.	B.	.038	.041
1201	1 : 1.26	B.	B.	B.	B.	.047	.055
1221	1 : 2.43	S.M.	B.P.	B.P.	B.	.035	.038
2001	1 : 1.75	B.	B.	B.	B.	.050	.057
2021	1 : 2.36	S.M.	B.P.	B.P.	B.	.036	.039
2201	1 : 1.75	B.	B.	B.	B.	.045	.051
2221	1 : 2.26	S.M.	B.P.	B.P.	B.	.038	.036
2401	1 : 1.75	S.M.	S.M.	B.	B.	.038	.044
2421	1 : 2.16	S.M.	S.M.	B.P.	B.	.028	.032
3001	1 : 1.68	B.	B.	B.	B.	.047	.053

B. – Bright B.I. – Bright, immature
B.F. – Bright, feathered B.P. – Bright, pin-holed
S.M. – Semi-mat

05-1, and 0.4 equivalents at cone 3. The oxygen ratios varied from 1 :1.07 to 1 :2.52.

Using our cost figures, the cheapest bright glazes found were:

Cone 05 ..... No. 2201
Cone 02 ..... No. 2201
Cone 1 ..... No. 2401
Cone 3 ..... No. 2421

TRANS. AM. CER. SOC. VOL. XIX STALEY & HEWITT

TABLE XIII – MAT GLAZES

No.	BATCH EQUIVALENTS					EMPIRICAL FORMULAE				
	Feld-spar	Whit-ing	White lead	Clay	Flint	K_2O	CaO	PbO	Al_2O_3	SiO_2
102	0.20		0.80	0.10		0.20		0.80	0.30	1.40
104	0.40		0.60	0.10		0.40		0.60	0.50	2.60
122	0.16	0.20	0.64	0.10		0.16	0.20	0.64	0.26	1.16
124	0.32	0.20	0.48	0.10		0.32	0.20	0.48	0.42	2.12
140		0.40	0.60	0.10			0.40	0.60	0.10	0.20
142	0.12	0.40	0.48	0.10		0.12	0.40	0.48	0.22	0.92
202	0.20		0.80	0.20		0.20		0.80	0.40	1.60
222	0.16	0.20	0.64	0.20		0.16	0.20	0.64	0.36	1.36
242	0.12	0.40	0.48	0.20		0.12	0.40	0.48	0.32	1.12
300			1.00	0.30				1.00	0.30	0.60
320		0.20	0.80	0.30			0.20	0.80	0.30	0.60
140.5			0.60	0.10	0.50		0.40	0.60	0.10	0.70
240.5			0.60	0.20	0.50		0.40	0.60	0.20	0.90
300.5			1.00	0.30	0.50			1.00	0.30	1.10
302.5	0.20		0.80	0.30	0.50	0.20		0.80	0.50	2.30
320.5		0.20	0.80	0.30	0.50		0.20	0.80	0.30	1.10
322.5	0.16	0.20	0.64	0.30	0.50	0.16	0.20	0.64	0.46	2.06
340.5		0.40	0.60	0.30	0.50		0.40	0.60	0.30	1.10
3401		0.40	0.60	0.30	1.00		0.40	0.60	0.30	1.60

The composition and textures of the mats developed are tabulated in Tables XIII and XIV. The mats classed as dull are typical mats of immaturity with dull, dirt-catching surfaces, and with a heat range, as mats, of only a few cones. They have no distinguishing point in composition. This type of mat is hard to control and has not a pleasing texture. The advisability of using it in commercial work is questionable.

The watery mats have rough, apparently crystalline, structure for the most part; but interspaced with this texture are little areas of bright texture. These areas are below the line of surface of the mat patches and have the appearance of being residual mother-liquor, left by the crystallization of the rest of the glaze. The points in composition common to the four glazes showing this texture is the presence of 0.4 equivalent of Ca O,

TRANS. AM. CER. SOC. VOL. XIX STALEY & HEWITT

TABLE XIV – MAT GLAZES

No.	Oxygen Ratio	Texture at Cone 05	02	1	3	Cost per lb. Raw	Melted	Type of Mat Dull	Watery	Notably Cryst.	Silky
102	1:1.47	M.	S.M.	B.	B.	$.044	$.048	✓			
104	1:2.08	M.	B.P.	B.P.	B.P.	.029	.031	✓			
122	1:1.30	M.	B.P.	B.P.	B.P.	.040	.045	✓			
124	1:1.87	M.	B.P.	B.P.	B.P.	.028	.030	✓			
140	1:0.307	M.	M.	M.	M.	.050	.062		✓		
142	1:1.66	1.	M.	M.	M.	.036	.042		✓		
202	1:1.45	1.	M.	M.	S.M.	.041	.045	✓			
222	1:1.31	1.	1.	M.	M.	.037	.042	✓			
242	1:1.14	1.	1.	M.	M.	.033	.039		✓		
300	1:0.63	M.	M.	M.	Dry	.055	.063			✓	
320	1:0.63	1.	1.	M.	Dry	.049	.058			✓	
140.5	1:1.07	M.	S.M.	S.M.	B.	.045	.056		✓		
240.5	1:1.12	1.	M.	M.	M.	.041	.049				✓
300.5	1:1.15	M.	M.	M.	M.	.051	.058				✓
302.5	1:1.84	1.	M.	M.	M.	.036	.039				✓
320.5	1:1.15	M.	M.	M.	M.	.045	.052				✓
322.5	1:1.73	1.	M.	M.	M.	.033	.037				✓
340.5	1:1.15	1.	1.	1.	M.	.038	.045	✓			✓
3401	1:1.68	M.	S.M.	S.M.	S.M.	.035	.041	✓			

M. – Mat 1. – Immature B.P. – Bright, pin-holed
B. – Bright S.M. – Semi-mat

no flint, and not over 0.2 equivalent of clay. For some purposes the texture would be considered artistic.

The two mats classed as visibly crystalline are smooth, the mat texture being caused by a net work of fine crystals, that are visible to the naked eye. These glazes are both high in clay and contain neither feldspar nor flint. The texture would be considered good.

The glazes classed as silky mats are smooth "soft" textured mats which do not retain dirt rubbed on the surface. Glazes 300.5 to 322.5 have 0.3 equivalent of clay and 0.5 equivalent of flint in common and not over 0.2 equivalent of Ca O. They are closely related in composition to those classed as visibly crystalline. Glazes 247.5 and 340.5 lie in composition between the other silky mats and watery mats. The silky mat is the one most sought by glaze makers. The textures of 240.5, 300.5, 320.5 and 340.5 are especially good. It is noteworthy that none of these contains feldspar.

A study of the compositions of the true mats developed in this investigation leads to the conclusion that the mats commonly designated as "lime-alumina" consist of two distinct classes: those high in lime, and those high in clay. Of course a whole series of mat compositions can be made by blends of these two types.

Leaving out of consideration all the dull mats, in other words mats of immaturity, the cheapest mats developed were:

Cone 05, No. 320.5, silky texture
Cone 02, No. 320.5, silky texture
Cone 1, No. 322.5, silky texture
Cone 3, No. 322.5, silky texture

The cheapest mats of especially good silky texture were:

Cone 05, No. 320.5
Cone 02, No. 320.5
Cone 1, No. 240.5
Cone 3, No. 340.5

The cheapest watery mats were:

Cone 05, No. 140.5
Cone 02, No. 142
Cone 1, No. 242
Cone 3, No. 242

PARTIAL LIST OF ARTICLES DEALING WITH RAW LEAD GLAZES IN THE TRANSACTOINS

Monosilicate Glazes By C. F. Binns, p. 151, Vol. II
Alumina and Silica, Permissible Variation of, in Raw Lead Glazes
By W. M. Fickes, p. 82, Vol. III
Greens from Cupric Oxide
By F. W. Walker, p. 278, Vol. IV
The Development of the "Matt" Glaze By C. F. Binns, p. 50, Vol. V
Coefficient Equivalents By S. G. Burt, p. 123, Vol. VII
A Comparative Study of Cornwall Stone and Feldspar in Raw Lead Glazes By L. B. Coulter, p. 356, Vol. VII
Spitting Out, A Phenomenon of the Decorating Kiln
By R. G. Cowan, p. 493, Vol. IX
A Study of a Type of Mat Glaze Maturing at Cone 2-4
By Edward Orton, Jr., p. 547, Vol. X
Mat Glazes By F. H. Rhead, p. 157, Vol. XI
Mat Glazes By Ross C. Purdy, p. 671, Vol. XIV
A Theory for the Cause of Matness in Glazes
By F. K. Pence, p. 682, Vol. XIV
Microscopic Examination of Twelve Mat Glazes
By Homer F. Staley, p. 691, Vol. XIV
Mat Glazes By F. K. Pence, p. 413, Vol. XV
Notes on the Cause of Matness in Glazes
By A. R. Heuback, p. 591, Vol. XV
Notes on Mat Glazes By A. P. Potts, p. 628, Vol. XV
A Study of the Relations Between Fusibility and Heat Range in Glazes By Homer F. Staley, p. 694, Vol. XV
Roofing Tile Slips and Glazes
By E. T. Montgomery and C. F. Tefft, p. 144, Vol. XVI
The Effect of Variation of RO Elements upon Chromium Oxide as a Coloring Agent in a Mat Glaze By R. H. Minton, p. 248, Vol. XVI
Oxide of Lead Versus Carbonate of Lead in Glazes
By A. S. Watts, p. 474, Vol. XVII
Galena and Lead-Bearing Waste Materials as Glaze Ingredients
By J. Miller, p. 779, Vol. XVII

Ceramic Engineering Laboratories,
Iowa State College

DISCUSSION SUBMITTED AFTER READING PAPER

Mr. Purdy: A study of table No. 12, of good bright glazes, shows that with his calculations the glazes with sufficient heat range as to be commercially advisable, range from 4.7c to 5.8c per pound raw. Of the seven glazes that are bright over the heat range of cones 05 to 3 inclusive, the average cost is 5c.

Of the matt glazes those he styles as watery range from 3.9c to 6.2c per pound raw, with an average of 3.9c. Those he styles as visible crystalline range from 5.5c to 4.9c average 5.2c. Those he styles as being silky range from 3.3c to 5.1c with an average of 4.01c per pound.

It will be noticed that these costs per pound of raw glaze are near the maximum cost of all of the glazes he tested. These are the glazes he found to be good over a long heat range.

No glaze is cheap if it has not sufficient range in all properties to meet the varying conditions of manufacturing, since the materials used are such a minor part of the total cost of ware and since the loss of the ware carrying one ton of raw glaze would pay for several tons of glaze. The most inexpensive glaze, irrespective of original cost, is that one which gives good results over the maximum range of variation in the given manufacturing. It is never a question of original cost of glaze but the minimum loss of ware.

Mr. Staley: What Mr. Purdy says is obviously true. In this work we had no ax to grind — no pet theory to uphold, and are therefore satisfied with whatever conclusions can legitimately be drawn from the data. We believe however that this investigation will help users of raw lead glazes to find the glaze that will give them the minimum loss of ware with the least cost for glaze materials.

INVESTIGATION OF THE TERNARY SYSTEM WILLEMITE-TEPHROITE SODA GLASS [1]

BY H. C. ARNOLD

The object of this work was to study microscopically those types of crystals, separating from a silicate fusion, which are used in the production of ceramic crystalline glazes, to determine their optical properties, and what relation of igneous solution to separated crystals is most conducive to their production.

Most of the crystal glazes described in the Transactions of the American Ceramic Society have been from glazes containing zinc in the RO and a small amount of TiO_2 included with the silica. Chas. Lanth, 1879, reports crystals in a glaze produced by adding ZnO alone to a developed glaze. He speaks of them as small crystals of the silicate, or more likely, the oxide. Clement of Copenhagen, 1898, describes the production of crystals on hard porcelain by the application of a second glaze of $SiO_2 + ZnO$. He claimed the crystals were willemite. Vogt also considers the crystals to be willemite. He, however, used rutile in his glazes.

Zimmer [2], in 1902, described his attempts to produce crystal glazes by using zinc oxide and silica. He concluded that TiO_2 was necessary to the production of good crystal glazes.

Stull [3] divides crystal glazes into two classes: —

(1) — Those in which crystallization is produced by supersaturation, or the separation of a dissolved oxide by decrease in temperature; (2) — those in which the entire mass has a crystalline structure including mats, and radial or crystal aggregate structure.

He also states (1) — that elements with low atomic weight in the RO show the strongest crystallizing tendency, while those of high molecular weight impart a glassy nature to the silicates;

[1] Review of a thesis done in partial fulfillment of the requirements for the degree of Master of Art at Ohio State University.
[2] *Trans. Amer. Cer. Soc., Vol. IV,* p. 43.
[3] *Trans. Amer. Cer. Soc., Vol. VI,* p. 186.

(2) — those elements in the acid radical of higher atomic weight (silica, uranium and phosphorous) are the best crystallizing agents while lower ones impart a fluidity which is detrimental to the production of crystals. He chooses a glaze corresponding to a metasilicate and changes his RO to fit conditions. He obtained his best results from a glaze of the formula $R_2O.R_2O_3.6$ acid. The ordinary mat glaze has a formula which is more complex, one which would place it between disilicate, and orthosilicate. A mat glaze will often reveal two or more crystalline forms belonging to two or more crystallizing groups or systems.

Riddle[4] produced zinc crystals without using TiO_2 by heating the glaze to maturity, cooling rapidly to cone 010 and holding at this temperature.

Purdy and Krehbiel[5] arrived at the following conclusions:

(1) — Of the two alkalies, potash and soda, the latter in every case was the most conducive to the development of crystals. The crystals in the soda matrix were not only the largest, but had the most pleasing habits of growth and grouping.

(2) — The proportion of zinc and alkali most conducive to the development of crystallization in every case, save that of glazes high in titanic acid, was:

$$\left.\begin{matrix} .3ZnO \\ .7KNaO \end{matrix}\right\} \text{ to } \left\{\begin{matrix} .6ZnO \\ .4KNaO \end{matrix}\right.$$

(3) — Manganese oxide had by far the greatest crystalliing tendency producing crystals not only large but also of surprising habits of growth. Zinc oxide had a tendency to produce large crystals in local areas, as though the crystallizing substance had segregated. Titanic acid produced small but evenly distributed crystals.

(4) — The character and shapes of the crystals induced by the manganese cannot be adequately described. The globular growths, that under the microscope were handsome, produced en masse an effect that was anything but pleasing. The concentric growth with the delicate spiral lines in lighter tints were superb and later fawn effect crystals were very beautiful.

[4] *Trans. Amer. Cer. Soc., Vol. VIII.*
[5] *Trans. Amer. Cer. Soc., Vol. IX.*

(5) — Limits of oxygen ratio permissible were not established. Results would indicate that an O. R. of 1 to 2.8 is better suited to the development of crystalline glazes than 1:4, as used in the present practice.

Rand and Schurecht [6] report the production of good crystals from the glaze

$$\left.\begin{matrix}.3Na_2O \\ .65ZnO \\ .05CaO\end{matrix}\right\} \left\{\begin{matrix}.05\ Al_2O_3 \\ .30\ B_2O_3\end{matrix}\right\} \left\{\begin{matrix}1.8\ SiO_2 \\ 0.2\ TiO_2\end{matrix}\right.$$

maturing at cone 4. TiO_2 produces smaller crystals but a finer network of them.

Klein and Brown [7] report the occurrence of three types of at crystals in the system Na_2O, ZnO and SiO_2,, one at 90 percent SiO_2, 10 percent ZnO; one at 10 percent ZnO, 50 percent Na_2O, 40 percent SiO_2; and the last at 60 percent ZnO, 40 percent SiO_2, corresponding to three types of crystal structures, — glassy, mat and crystalline. In the mat and crystalline melts, the zinc orthosilicate corresponding to the mineral willemite separates out.

As it was desired to study this field from a mineralogical standpoint, we decided to recalculate Purdy's field on the basis of mineral content, and to make up a ternary field of soda glass, willemite and tephroite (manganese orthosilicate).

Willemite as it is found in nature contains as high as 12.59 percent manganese in the variety known as troostite. Dana [8], under composition, says: "Manganese often replaces a considerable part of the zinc, and iron also is present in small amounts." His analyses range from .37 percent to 12.59 percent manganese in the naturally occurring mineral.

In tephroite, the orthosilicate of manganese, we find a similar condition. Dana [9] in his analyses gives the range of zinc from .27 to 11.61 percent. Rhodonite, the triclinic metasilicate, shows the same characteristics.

---

[6] *Trans. Amer. Cer. Soc., Vol. XVI.*, p. 345.
[7] *Trans. Amer. Cer. Soc., Vol. XVII*, p. 461.
[8] Dana *System of Mineralogy*, p. 461.
[9] Dana *System of Mineralogy*, p. 4.

Since the occurrence of these minerals indicates that one is capable of dissolving a certain amount of the other, one would expect a curve of partially miscible liquid. The two minerals do not crystallize in the same system, and complete isomorphism would not be present. Chemical analyses would have to be made on the crystals formed, or changes in their optical properties noted, in order to determine the extent of mutual solubility.

The curves shown in Figures 1 and 2 show the recalculation of Purdy's field of $ZnO \cdot SiO_2 \cdot Na_2O$, and $MnO \cdot SiO_2Na_2$ glazes, as percentage mineral in a certain glass. The molecular ratio $\frac{SiO_2}{Na_2O}$ is plotted as the abscissa and the percentage of orthosilicate present as the ordinate. On these curves Klein's best glazes have been located. In both the zinc orthosilicate and the manganese orthosilicate the largest proportion of good glazes lay within a circle whose center corresponds to a glass of the formula $Na_2O.2.5\ SiO_2$, while Klein's corresponded to $Na_2O.2SiO_2$. As Klein's conditions more closely duplicated those of the present work it was decided to use $Na_2O.2SiO_2$ as the third component in the system. Figure 3 shows the field covered.

The three corner members were prepared synthetically, and fused to a glass in fire clay crucibles in a gas-air pot furnace, and quenched in water. They were melted to remove as far as possible, all crystalline material before the other batches were made up. Under the microscope the willemite glass showed a few crystals which correspond optically to the mineral willemite. The tephroite, however, showed crystallization of a mineral which agreed more nearly with the metasilicate rhodonite.

The melts were then analyzed for their individual components, to determine the loss by volatilization. ZnO in the willemite, which should have been 73 percent, was 59.6 percent; MnO in the tephroite should have been 70.3 percent, and was 61.8 percent. The glass had not changed composition. The

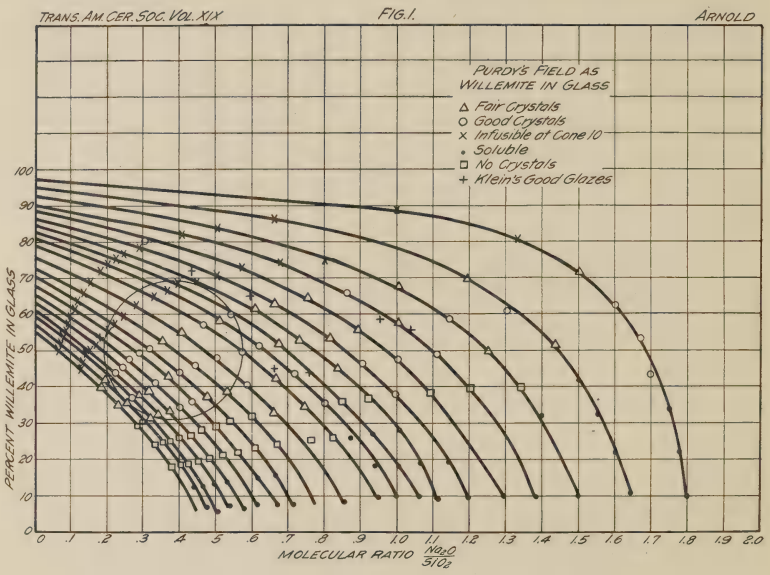
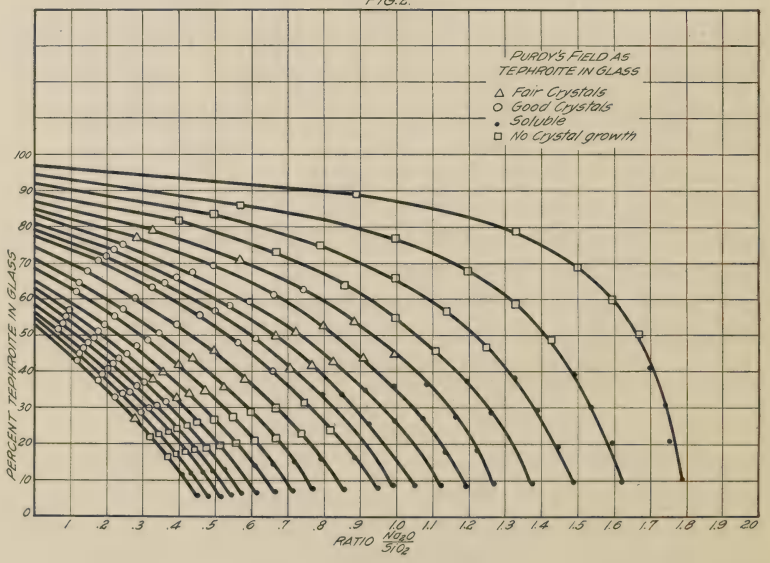
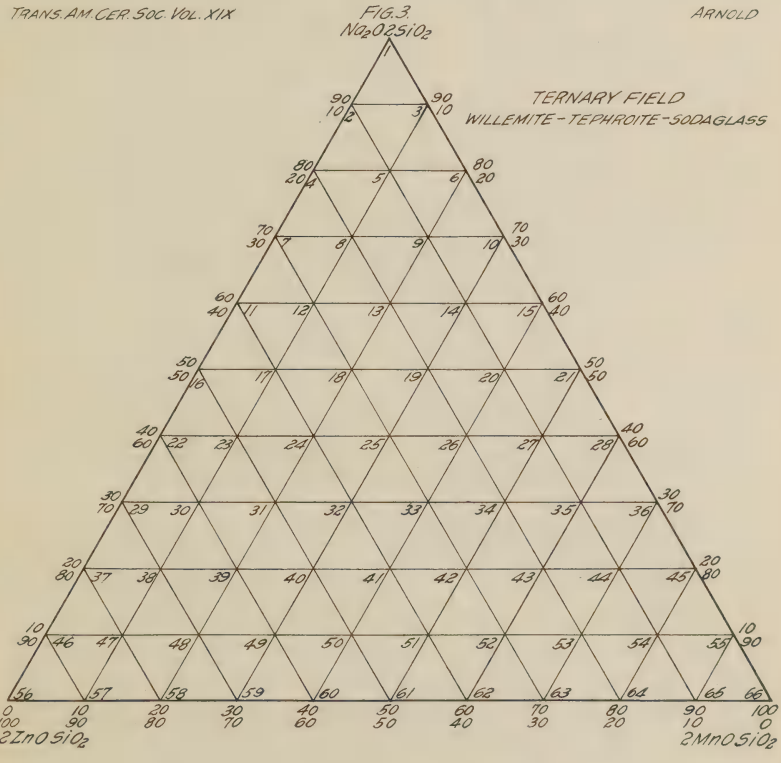

TRANS. AM. CER. SOC. VOL. XIX
FIG. 1.
ARNOLD
PURDY'S FIELD AS WILLEMITE IN GLASS
△ Fair Crystals
○ Good Crystals
× Infusible at Cone 10
• Soluble
□ No Crystals
+ Klein's Good Glazes
PERCENT WILLEMITE IN GLASS
MOLECULAR RATIO Na2O / SiO2

FIG. 2.

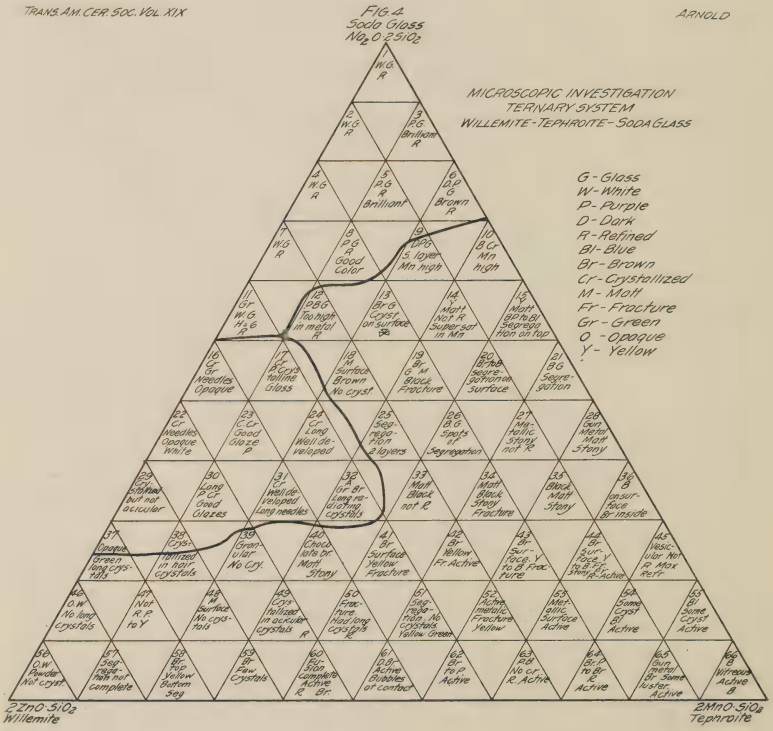

PURDY'S FIELD AS TEPHROITE IN GLASS
△ Fair Crystals
○ Good Crystals
• Soluble
□ No Crystal growth
PERCENT TEPHROITE IN GLASS
RATIO Na2O / SiO2

loss from ZnO was added to the individual members as ZnO, and the MnO, as MnO_2, making a maximum of five components to each member, willemite, tephroite, zinc oxide, manganese dioxide, and soda glass. All were screened through a 60-mesh before mixing and then mixed three times through a 20-mesh. The trials were weighed out accurately to the second decimal



place, and placed in cork stoppered bottles. Each trial was numbered as shown in Figure 3. Melts corresponding to numbers 1 to 29 inclusive were heated in porcelain crucibles in a nichrome furnace to 1175°C. in three and a half hours. Gas evolution started at 880°C. and continued in the different members to 1063°C. At 1175°, the furnace burned out, and consequently cooling took place rapidly. All the crucibles were shat-

tered. For the most part a pure glass was developed. Their macroscopic properties are given in Fig. 4, and their microscopic properties in Fig. 5. Trials 1 to 9 developed a pure completely refined glass, with a beautiful purple color whenever they contained manganese. From 9 to 15 the structure was still glassy and refined [10], but over the surface of the glass there was a thin sub-metallic coating. Crystallization in the zinc series begins



with glaze 16. The crystal development was not pronounced, but the fracture was granular showing that devitrification had taken place. This crystallization disappeared as the ZnO decreased, the MnO producing a pure glass, sub-metallic on the surface but almost pure black on the fracture. Visible crystallization begins at 22 and extends to 25 in the series. Melt

[10] Refined refers to clear glass free from bubbles.

25 showed the same glassy rupture, but had patches of brown and purple throughout the mass. Melt 26 showed the same tendency to a greater degree; the separated products were very distinct and visible. Melts 27 and 28 showed the same property, but to a more limited extent.

Under the microscope the glasses showed complete isotropism down to number 16. At series 11-16, the glass seemed to have thrown off some of the manganese which was present as regularly arranged opaque black crystals. Whether this was due to recrystallization, or to undissolved material is hard to say. The idiomorphic form of the crystals would indicate recrystallization. Those members along the manganese orthosilicate boundary were the ones which showed this property. In those fragments which contained the separated substance there was little color. It appeared as though the crystals had drawn up all the coloring matter, and separated out as a mass, rather than diffusing through the whole glass.

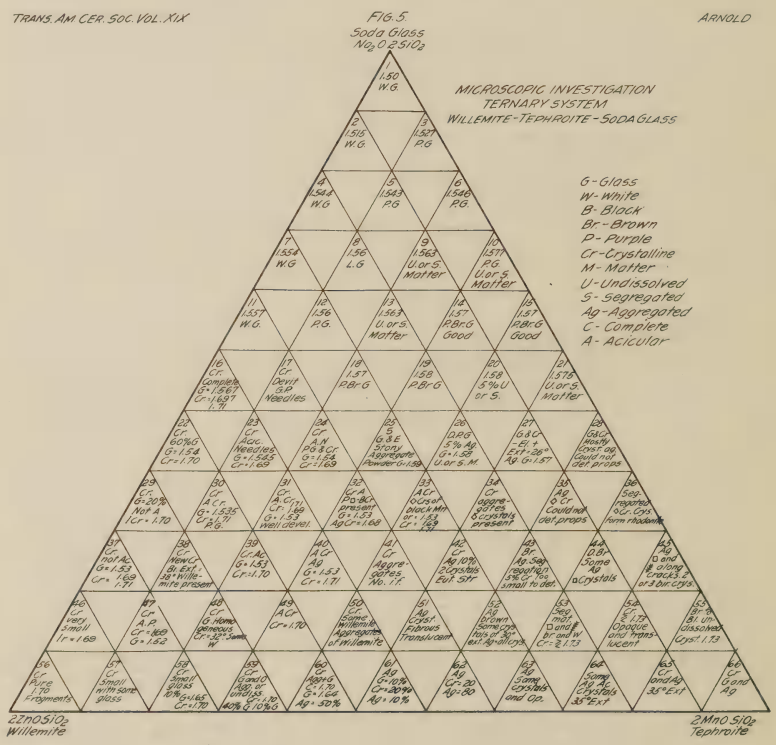
With increasing content of willemite and tephroite, the index of refraction of the glass increased. At the point where crystallization commenced, however, the index decreased again.

Melt number 16 was the first member to show anisotropism. The crystals were shot through the glass in parallel directions in elongated needles. Index of refraction of the ordinary ray was 1.69, extraordinary ray 1.71, sign positive, birefringence .018. Melt 17 showed about 5 percent crystallized willemite, 10 percent separated manganese, and 85 percent glass. As the amount of glass decreases, the crystallization and segregation increases. In number 21 it amounts to almost 40 percent of the material. The tephroite side showed no crystallization up to number 28.

As the cooling had been very rapid it was decided to remelt all those members in which crystals had the best opportunity of forming. Accordingly from 11 to 66 were placed in small fire clay crucibles, set in sand in a sagger, burned to cone 12 bending in 24 hours, and cooled for 62 hours. The macroscopic and microscopic results are shown in Figures 4 and 5.

The development of desirable long acicular crystals seems to occur best when the willemite makes up only about 50 per-

cent of the melt. The remaining 50 percent may be a pure glass or a mixture of manganese silicate and glass. At the temperature of this burn no visible crystals were developed with less than 40 percent willemite nor more than 70 percent. The manganese seems to act as a colorant, and to take no particular part in the formation of the crystals. At the end of the series hav-



ing high glass, completely refined glasses were formed. The manganese produced a beautiful color, which first changed to black and then produced a superficial coating.

Evidence of immiscible liquids was found in various parts of the field. Melt number 25 separated completely into two layers, one a dark purple black, glassy substance, and the other a brown, stony, opaque material. Figure 11 shows a cross sec-

tion through the middle of the melt. The line of separation is very definite. The form would indicate that the lower layer was one of very high surface tension. It had drawn up nearly to a sphere. Melt number 26 showed the same content of stony material but in a decidedly decreased amount.

In this melt, small drops of the stony material were scattered through the melt. The decrease in the amount present leads to the belief that the stony layer contains the zinc content and the glassy layer the manganese content. The two trials preceding 25 were both well crystallized. Figure 6 taken from melt

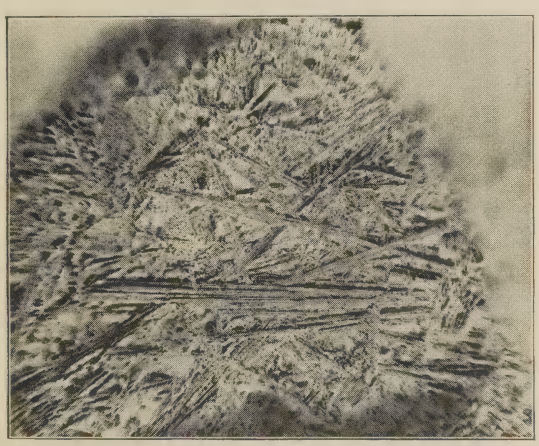


FIG. 6. Willemite Crystals in Mass

31, shows their general structure. Figure 7 shows one or two crystals that had grown completely out of the melt. Under the high power lens these crystals appear as though they had liquid inclusion. They possess hexagonal cross section. Figure 8 is a picture of the same crystal under crossed nicols. They show parallel extinction, and high birefringence. Judging from the shape of the end of these crystals one would say that the liquid had high surface tension.

At the high willemite corner, with low glass, the trials became dull and granular. There was a slight development of the long acicular type of crystal, none on the surface, but pene-

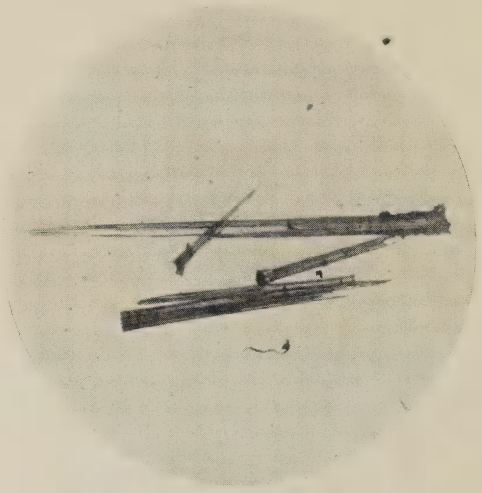


FIG. 7. Individual Crystals of Willemite

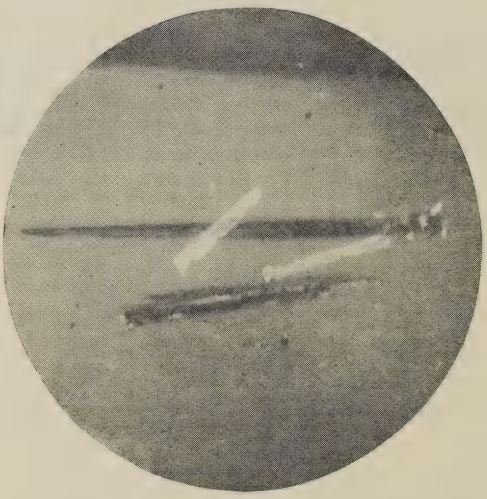


FIG. 8. Same as Figure 7 With Crossed Nicols

trating the interior of the mass. (See Fig. 9). Evidence of segregation continued to show just inside of the willemite-soda glass series. The content of glass here did not appear sufficiently high for the production of crystals. The crystallization is very fine, as though numerous centers had been set up, and the long crystals had not had an opportunity to develop.

As the tephroite increased the melts became more active. The walls of the crucible, at the point of contact with the surface of the melt, were slagged clear through, and the refractoriness of the melt seemed to decrease toward pure tephroite.

Under the microscope those members which showed the most desirable crystal development at the surface consisted of a glass matrix in which crystals had grown; they were in parallel growths, short and long, thick and thin. As the content of glass decreased, this parallel arrangement was destroyed. The crystallization occurred in minute fragments, more like bubbles or cells. It appeared as though with the increase in crystallizing substance, crystallization starts at a great many more places, and the conditions are not favorable to the development of long crystal individuals.

In the case of the soda glass-tephroite series, the upper end of the series showed complete isotropism. With increase in manganese the purple color changed to a purple brown. At No. 20 a separation of black substance was noted in the glass, which was hard to determine whether undissolved or recrystallized. It appeared to have a idiomorphic diamond or square shape and to separate in long branches which would suggest recrystallization. (See Fig. 10).

On decreasing the glass along each series, a eutectic seems to develop which is cryptocrystalline. It was brown in reflected light and a dull white in transmitted light. Toward the willemite end of the series this material would be attached to and mixed in with the willemite crystals. At the tephroite end the black idiomorphic crystals separated out up to number 25. At this point they were accompanied by another crystalline substance having an extinction angle of 28 to 32°, index about 1.73.

Along the lower two series the amount of crystallized substance increased and characterized 53, 54, 55, 63, 64, 65 and 66. Crystallization was always accompanied by the idiomorphic black crystals, resembling magnetite in igneous rocks.

In order to verify crystal separation and to determine more effectively what relations exist between the different members of the system, it was decided to determine cone deformation temperatures on the various melts as an indication of the eutectic point and the formation of deformation maxima.

FIG. 9. Parallel Willemite Growth Radiating From a Center

One inch cones of each mixture were heated to their softening points in a small nichrome furnace; observations were made on the deformation temperature both at the time deformation started, and when it ended. If the mixture represented a pure compound or a eutectic composition, we would expect a very small range of deformation, but if the composition were in the field of a solid solution the range of deformation would be large; the cone would pass through a long pasty range. In this way they might indicate the relations of the components in the melt, but of course would not establish them.

To fix them definitely would require a series of quenching experiments, and a study of the resulting crystals.

The temperatures of deformation were noted on a platinum-platinum rhodium thermocouple. Where the cone was too refractory to melt in the nichrome furnace a small platinum furnace was used. Figures 12, 13 and 14 and 15 show the deformation temperatures for the whole field, and for the binary systems surrounding the ternary system. Melt No. 12 had the lowest deformation temperature; it is directly opposite the glass-willemite eutectic, and one removed from the glass-tephroite

FIG. 10. Crystallized Tephroite With Hausmannite

eutectic. The general parallelism of the lines would indicate that the decrease in glass from series 11-15 down increases the refractoriness of the melt. The point of highest deformation temperature along the glass-tephroite series was not at the corner but at No. 45. Evidence so far presented would indicate the crystallization of a manganese oxide, such as hausmannite, and the metasilicate, rhodonite, instead of tephroite.

Figure 15 indicates the willemite-tephroite curve. The upper curve represents the temperature of complete deformation and the lower, the beginning of deformation. The result is, of course, rough and merely indicates the present trend of the curve. Fur-

ther work is to be done on this series, which may locate the exact position of the curve.

In order to verify the results along the glass-tephroite series the members were made up again and studied in quenching experiments. A series was made as follows:

	1	2	3	4	5	6	7	8	9	10	11	
$Na_2O.2SiO_2$	100	90	80	70	60	50	40	30	20	10	0	
	0	10	20	30	40	50	60	70	80	90	100	$2MnO.SiO_2$

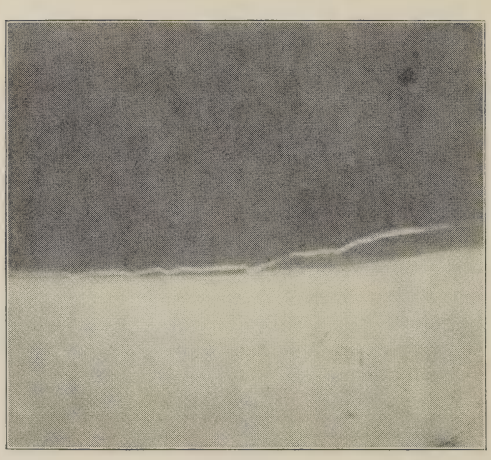
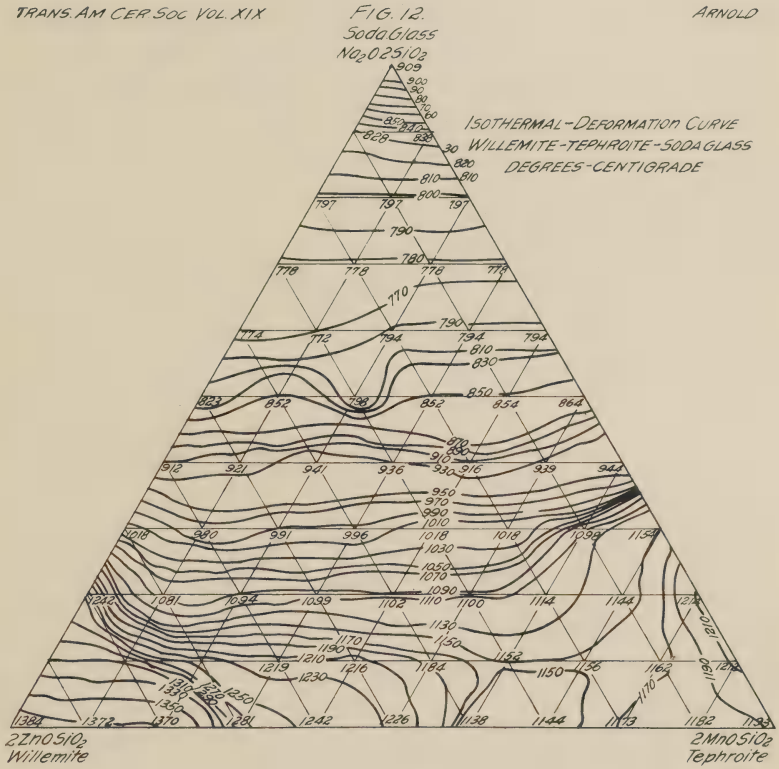


FIG. 11. Line of Separation of Segregated Material

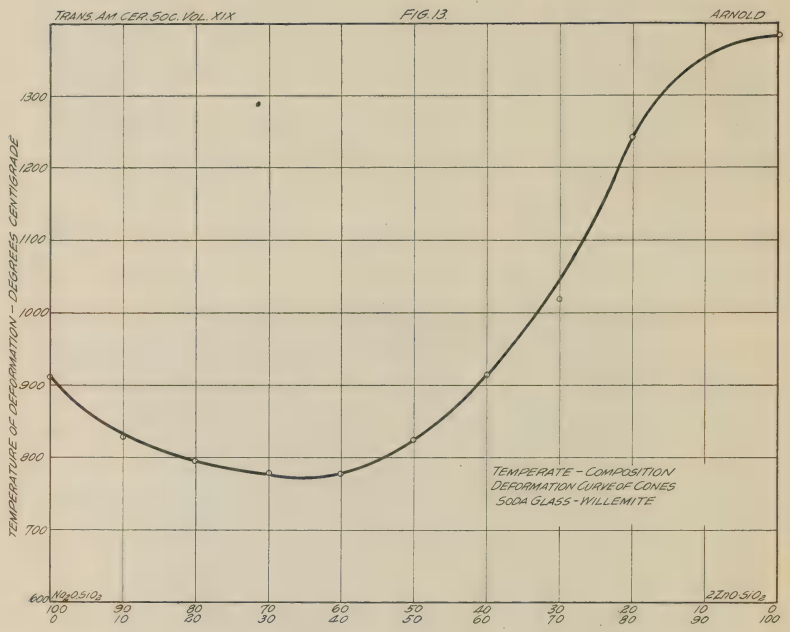
Members numbers 1 and 11 were prepared synthetically, heated to fusion in a graphite crucible, and the contents quenched. Correction was made for volatilization in the case of the tephroite, but none was required for the glass. In this case the extra manganese required was added as the carbonate, so that any separation could be identified as recrystallization. Optically No. 1 showed complete isotropism, but the tephroite could not be quenched quickly enough to prevent crystallization. Index of refraction of the soda glass was 1.495. The index of refraction of the crystalline tephroite was greater than 1.75, sign negative.

Each member of the series was then made up, fused to a glass in a platinum crucible and quenched in water. By using

a platinum crucible it was possible to have the melt retain its original composition. The results are shown in Fig. 16. In order to trace out the temperature composition curve and investigate the maximum shown on the deformation curve, it was decided to run cooling curves on those melts which were sufficiently fluid to allow determinations to be made. Such a curve



is shown in Fig. 14. Members 11, 10 and 9 were the only ones which gave lag points in their cooling curves. They were enough, however, to show that no indifferent point coincided with the deformation maximum. Those members which did not yield a lag in their cooling curve were held for from three to six hours at a temperature where an inserted wire could just


TRANS. AM. CER. SOC. VOL. XIX
FIG. 13.
ARNOLD
TEMPERATURE OF DEFORMATION - DEGREES CENTIGRADE
1300
1200
1100
1000
900
800
700
600
TEMPERATE - COMPOSITION DEFORMATION CURVE OF CONES SODA GLASS - WILLEMITE
$Na_2O.5iO_2$
$2ZnO.SiO_2$
100 90 80 70 60 50 40 30 20 10 0
0 10 20 30 40 50 60 70 80 90 100

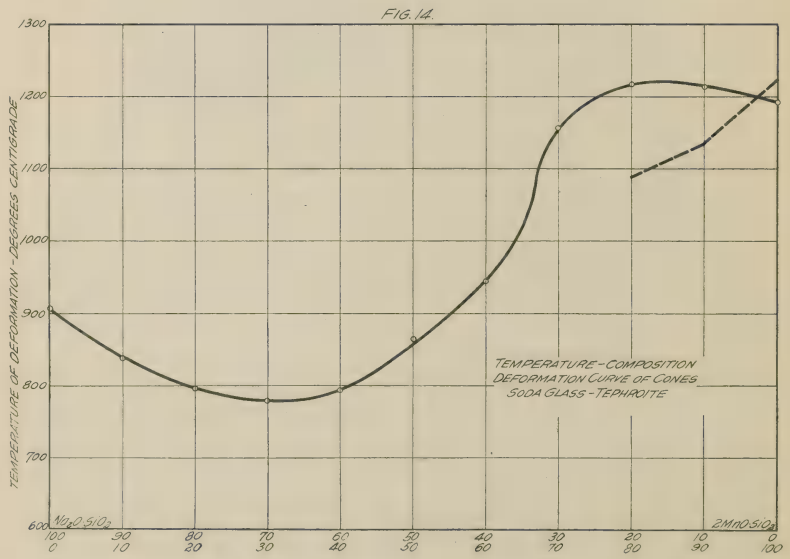
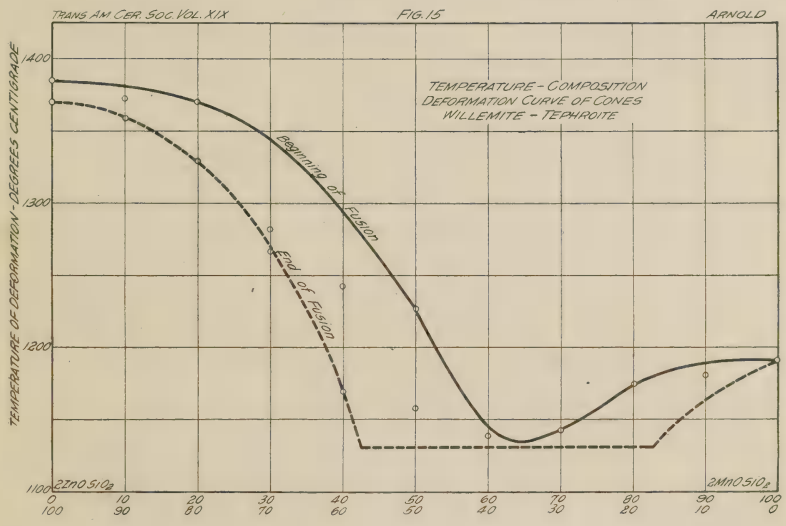


FIG. 14.
TEMPERATURE OF DEFORMATION - DEGREES CENTIGRADE
1300
1200
1100
1000
900
800
700
600
TEMPERATURE - COMPOSITION DEFORMATION CURVE OF CONES SODA GLASS - TEPHROITE
$Na_2O.5iO_2$
$2MnO.SiO_2$
100 90 80 70 60 50 40 30 20 10 0
0 10 20 30 40 50 60 70 80 90 100

be moved up and down. Results of the slow cooling are shown in Fig. 17.

Slow cooling greatly increases the amount of crystalline matter formed. From the optical study it is evident that the black mineral is the most insoluble form of manganese present. That compound of manganese with which it most closely agrees is the oxide hausmannite, Mn_3O_4 or $MnO.Mn_2O_3$. This compound is analagous to the iron oxide, magnetite, which we know is one of the first substances to crystallize out in an igneous rock magma. Dana [11] describes hausmannite as having an



octahedral habit with characteristic crystals, brownish-black color, and is found in veins of porphyry. Doelter [12], in describing the synthesis of tephroite, speaks of its occurrence accompanied by hausmannite and rhodonite. This would suggest hausmannite as the black mineral, and in the absence of any evidence to the contrary we have called the mineral hausmannite.

In the slowly cooled mixes, hausmannite was developed in No. 3, and showed an increasingly large development up to the

[11] Dana *System of Mineralogy*, p. 230.
[12] Doelter — *Handbuch der Mineralchemie*, *Vol. 2; part 1*, p. 714

last member. When quickly cooled, however, there was no evidence of hausmannite until No. 7 was reached. Tephroite in the slowly cooled melts developed first in No. 8, and in the quickly cooled melts in No. 9. From such data one may conclude that hausmannite is the most insoluble form of manganese in a silicate fusion; that rhodonite forms when the mass has an opportunity of accumulating more silica, and that tephroite forms last from the fusion.

The following conclusions may be derived from the results obtained:

(1) — The conditions which is most conducive to the development of the commercially desirable crystals of willemite is the presence of about 50 percent willemite and 50 percent glass in which the crystals can grow.

(2) — Higher amounts of willemite produce small undeveloped crystals with few or no large desirable crystals.

(3) — Crystallization from a silicate fusion containing manganese is not so definite as from one containing zinc. Three compounds of manganese are produced: (1) hausmannite, (2) rhodonite, (3) tephroite. When the mass is free to attack siliceous material, rhodonite is usually formed instead of tephroite. Hausmannite is the first to form, and seems to be the most insoluble in the silicate melt.

(4) — With long heating at a temperature of moderate viscosity, the development of hausmannite is greatly increased.

(5) — The evidence obtained from the deformation of cones, and from the occurrence of immiscibility indicates a limited isomorphous crystallization along the willemite-tephroite line. However, no definite conclusions can be drawn from these few facts. Later work is to be done which we hope will complete this binary system.

FIGURE 16.

MICROSCOPIC INVESTIGATION OF THE QUICKLY COOLED SERIES SODA GLASS — TEPHROITE.

2 Deep violet glass. Powder a light purple color well disseminated. Fracture show Mn color.

3 A dark purple much stringier. Still glassy. High viscosity. Powder darker than 2. Still purple.

4 Not homogeneous color. Parts are a dark brown and yellow. Some purple. Powder is lighter in color.

5 Dark and stringy. Slivers show brown purple. Color black. Powder is a dirty brown, deeper than 4 with more brown.

6 Pilchy brown like resin. Stringy. Powder is a yellowish white. Similar to powdered pitch.

7 Same color as 6. Stringyness gone. Glassy. Powder darker than 6 yellowish white. Some dark places.

8 Glass appeared a jet black; a dark brown on fractures. Gives a dull brown surface in spots. Powder is darker; very sharp change.

9 Surface becomes a dull brown with some jet black. Has slaggy appearance. Powder a darker chocolate, but same appearance.

10 A dull, dark brown. Slaggy. No stringyness. Powder same as 9, a dark chocolate brown.

11 Dull, metallic slag. Hard. No viscosity. Hard to melt. Powder is coffee brown. Acted more as a metal than a glass.

FIGURE 16-A.

Microscopic Investigation of the Quickly Cooled Series Soda Glass — Tephroite.

2 Completely isotrophic glass, a delicate violet color, with index refraction. 1.51. Particles angular.

3 Isotropic; deeper purple but homogeneous. I. r. = 1.53. Angular fragments. No crystalline properties.

4 Color not uniform. Purple is 5 percent. Remaining glass is colorless, isotropic in nearly all cases. Segregation of color.

5 All colored a dark-brown purple; color well distributed. One or two brown. No cyrstallization. I. r. = 1.54.

6 A light greenish-yellow with 1 or 2 percent of dark brown pieces. Mostly colorless. Glossy fracture. Isotropic. Index high. = 1.56.

7 Yellowish green; a few dark ones. Showed separated Mn_3O_4. First sample to show separated crystals. Index 1.57.

8 A rich, dark brown with some hausmannite. Color disseminated. Glossy structure. Index 1.57.

9 Abundant hausmannite; some glass; distinct crystallization but small particles. Negative. Index high. First crystallization found.

10 Large amount of hausmanite. Lots of crystallized material of high index. No glass. Either hausmanite or tephroite.

11 All crystallized. Hausmanite, and tephroite. Mostly the hausmanite surrounded with tephroite.

FIGURE 17.

MICROSCOPIC INVESTIGATION OF THE QUICKLY COOLED SERIES SODA GLASS — TEPHROITE.

2 Heated as high as 990° and held for 5½ hours. Sticky at 770°; flowed together; got softer up to 890° where it easily formed cords. Very sticky. Quenched after 5½ hours to a light transparent glass, of a dark purple color. Powder a light purple. In microscope showed a light purple glass almost colorless. Homogeneous. Isothropic. No sign of crystallization. Index = 1.53.

3 Heated up to 900° and held for 3½ hours. Sticky and viscous at 860°. Threads were a dark purple. Showed no evidence of crystallization. Quenched to darker, brilliant purple glass; hard. Powder a light purple slightly darker than 2. In microscope showed a purple glass with only a few traces of hausmanite. Mostly a purple glass index = 1.55.

4 Heated to 890° and held for 4 hours. Soft and sticky at 730°. Fragments had not lost their shape. Drawn out into threads. Soft at 890°; not so sticky. Quenched. A brilliant dark purple glass. Powder a brown purple. In microscope a purple glass but penetrated with small amounts of H. The slower cooling has increased the separation of H. For so small an addition crystallization is large.

5 Heated to 900° and held for 3 hours. Was soft as low as 730° and viscous. When quenched from 900° the particles, although very soft, had not lost their shape. Quenched to a jet black glass, brilliant in places, dull in others. Has glassy look. Powder a dark purple. In scope a purple glass preponderates. Nearly all particles have parts of H imbedded. Skeleton growth common. Some pieces pure black. Development rather good.

6 Heated as high as 1000°; held at 900° 4 hours. Was soft at 780° and sticky; remained viscous up to 1000°. When quenched particles had not lost form. Brown color like coffee grounds. Hard and cindery. Powder a dark brown. In scope purple glass. H. present in large amounts. Not so well developed. No sign of T. Where H. has not formed, the color is a dark purple; where it has a light purple. H. is most insoluble.

7 No lag. Heated to 1100°. Held at 870° for 4½ hours. Softened at 800°. Retained form up to 1000°; sticky and viscous. Flowed at 1100°. Quenched to a purple vitreous material; not glassy. Powder a light brown. In scope was a glass with a large amount of H. but a very small amount of T. Glass is purple. Some bubble formation of T, but sample was mostly glass with imbedded H.

8 No lag. Hard at 920°. Held at 950° for 2 hours. Wire would just penetrate and stuck fast when left in it. Quenched to a dark purplish brown with a vitreous luster. Hard. No indication of a glassy nature. Powder a brown. In scope mostly glass in which H. is imbedded. Some T. but only grains or centers with no large development. H. ideomorphic glass a purplish brown. Crystals are small.

9 Cooling curve shows lag at 1090°. Held at 1070° for 2 hours and quenched. A dark, vitreous brown. Hard. Has a slightly higher vitreous luster than 10. Powder a light brown. In scope more glass than 10, more id. H. and long bubble forms of T. than in 8. Are not developed solidly as in 10 and 11. Glass, a dark brown, acts as on imbedding material for the crystallization of these substances.

10 Lag at 1136°. Held at this temperature for 1 hour and quenched. A dark brown submetallic luster. Powder a dark brown. In scope some glass with interpenetrating crystallization of H. and T. T. crystallizes like drops of oil in the glass. H. has id. form. Abundant dark brown glass. Glass has index less than 1.75. Mineral greater than 1.75 branched, diamond shaped and rectangular growths of H.

11 Lag at 1220°. Held here for 1 hour and quenched. A dark brown-black, vitreous, hard substance with homogeneous brown granular appearance. Powder is a dark brown. In scope a large amount of idiomorphic H. in a dark glass. In similar fragments will be found T. and H. crystallizing together. Little glass, large amount of H., and most T. in any member.

H = hausmannite.
T = tephroite.
Scope = Microscope.

INDEX

Absorption—Effect of Pressure in the Forming of Dust Pressed Tile, 94.

Annealing—Paving Brick from Blast Furnace Slag, 507.

Anorthite—A Study of Three Component Normative Systems in Raw Lead Glazes, 312.

Apatite—Apatite, a Substitute for Bone Ash, 125.

Arnold, H. C.—Investigation of the Ternary System Willemite, Tephroite, Soda Glass, 674.

Art Pottery—The Development of Ceramic Decorative Processes, 449.

Arsenic—Use of Arsenic in the Fining of Glass, 201.

Ball Clays—American Clays for Floating Enamels, 339; The Burning Properties of Some American Refractory Clays, 246; Properties of Some American Bond Clays, 601; The Relation of Salt to Clay in the Purification of Clays, 460.

Barium—A Deformation Study of $BaO - Al_2O_3 - SiO_2$ Mixture, 457.

Barringer, Lawrence E.—Presidential Address, 69.

Binns, Charles F.—The Crawling of Mat Glazes, 597.

Blair, Marion W.—The Manufacture of Promenade Tile, 361.

Bleininger, A. V.—The Properties of Some American Bond Clays, 601.

Blending—Advantages of Clay Storage and the Description of a Successful Installation, 102.

Bodies—The Effect of Variation in Pressure and Moisture upon the Forming of Dust Pressed Tile, 409; The Effect of the Porosity of the Body and the Moisture Content of the Glaze in the Application of Mat Glazes, 428.

Bone China—Apatite, a Substitute for Bone Ash, 125.

Bone Ash—Apatite, a Substitute for Bone Ash, 125.

Bricks—Volume Changes of Some Commercial Silica Bricks on Heating, 83; Advantages of Clay Storage and the Description of a Successful Installation, 102; Paving Brick from Blast Furnace Slag, 507.

Bristol Glazes—A Deformation Study of $BaO - Al_2O_3 - SiO_2$ Mixture, 457; A Deformation Study of $MgO - Al_2O_3 - SiO_2$ Mixture, 453; A Study of Raw Lead Glazes, 312; A Practical Application of Bristol Glazes Compounded on the Eutectic Basis, 301.

Bubbles in Glass—Principles Controlling the Formation and Removal of Bubbles in Molten Glass, 201.

Burning—The Burning Properties of Some American Refractory Clays, 246; Heat Balance of a Continuous Tunnel Kiln, 216; A New Principle in Temperature Measurement, 260; Relation of

Fusing Point of Ash to Availability of Coal for Burning Ceramic Wares, 488.

Burning Behavior—The Properties of American Bond Clays, 601; Temperature, Porosity, Volume Changes of Some Porcelain Bodies, 636.

Burning Shrinkage—Effect of Variation of Pressure in the Forming of Dust Pressed Tile, 94.

Burning of Ware—The Crawling of Mat Glazes, 597.

Casting—Production of Special Refractories—Marquardt Porcelain and Magnesium Aluminate, 407.

Ceramic Education—Presidential Address, 76.

China—Apatite, a Substitute for Bone Ash, 125; A Study of the Physical and Chemical Properties of Three Compounds of Lead and Their Use in Raw Lead Glazes, 442; Temperature, Porosity, Volume Changes of Some Porcelain Bodies, 636; The Use of Sulphuric Acid in the Sedimentation of Kaolins, 130.

China Clay—The Use of Sulphuric Acid in the Sedimentation of Kaolins, 130.

Chrome—Chrome Tin Colors at Cone 9, 378.

Clare, R. L.—Causes for the Failure of Terra Cotta in the Wall, 593.

Clay—Advantages of Clay Storage and the Description of a Successful Installation, 102; American Clays for Floating Enamels, 339; The Burning Properties of Some American Refractory Clays, 246; The Development of Ceramic Decorative Processes, 449; Flow of Clay Through Hollow Ware Dies, 479; An Instrument for Measuring Plasticity, 523; Properties of Some American Bond Clays, 601; The Relation of Salt to Clay in the Purification of Clays, 460; The Relation between the Fusion Point and Composition of Refractory Clays, 303; Recent Improvements in Methods of Terra Cotta Mold Making, 585; Use of Sulphuric Acid in the Sedimentation of Kaolins, 130.

Clay Elevator—Wet Clay Elevator, 484.

Clay Storage—Advantages of Clay Storage and the Description of a Successful Installation, 102.

Clay Washing—The Use of Sulphuric Acid in the Sedimentation of Kaolins, 130; The Relation of Salt to Clay in the Purification of Clays, 460.

Coal—Relation of Fusing Point of Ash to Availability of Coal for Burning Ceramic Ware, 488.

Colors—Note on Overglaze Colors at Cone 6-7, 653.

Continuous Tunnel Kiln—Heat Balance of a Continuous Tunnel Kiln, 216.

Crawling—The Crawling of Mat Glazes, 597.

Cristobalite—Volume Changes of Some Commercial Silica Bricks on Heating, 83.

Crystal Glazes—Investigation of the Ternary System, Willemite, Tephroite, Soda Glass, 674.

Davis, N. B.—Apatite, A Substitute for Bone Ash, 125.

Defective Terra Cotta—Causes for Failure of Terra Cotta in the Wall, 594.

Deflocculation—The Relation of Salt to Clay in the Purification of Clays, 460; The use of Sulphuric Acid in the Sedimentation of Kaolins, 130.

Deformation—The Relation Between the Fusion Point and the Composition of Refractory Clays, 303; The Fine Grinding of Refractory Materials Before Testing, 534.

Deformation Temperatures—A Deformation Study of $MgO - Al_2O_3 - SiO_2$ Mixture, 453; A Deformation Study of $BaO - Al_2O_3 - SiO_2$ Mixture, 457.

Dehumidifier—Humidity, Its Control and Relation to the Drying of Clay Wares, 554.

Denmead, W. A.—Humidity, Its Control and Relation to the Drying of Clay Wares, 538.

Dies—The Manufacture of Promenade Tile, 361; The Flow of Clays Through Hollow Ware Dies, 479.

Discoloration—Discoloration of Kaolin by the Use of Sulphuric Acid in Washing, 141.

Dolomite—In the Magnesite Deposits of the Grenville District, Quebec, 254.

Dryers—Humidity, Its Control and Relation to the Drying of Clay Ware, 538.

Drying—Humidity, Its Control and Relation to the Drying of Clay Wares, 538.

Drying Shrinkage—The Properties of Some American Bond Clays, 601.

Electrical Porcelain—Humidity, Its Control and Relation to the Drying of Clay Wares, 538.

Electrolytes—The Relation of Salt to Clay in the Purification of Clays, 460.

Elevator—Wet Clay Elevator, 484.

Emley, Warren E.—An Instrument for Measuring Plasticity, 523; Measurement of the Time of Set of Calcined Gypsum, 573.

Enamels—Enamel Surfaces under the Microscope, 146; American Clays for Floating Enamels, 339.

English Ball Clay—American Clays for Floating Enamels, 339.

Eutectics—The Practical Application of Bristol Glazes Compounded on the Eutectic Basis, 301.

Expansion—Volume Changes of Some Commercial Silica Bricks on Heating, 83.

Fettke, Charles R.—Glass Sands, 160.

Fire Brick—The Burning Properties of Some American Refractory Clays, 246; The Effect of the Size of Grog in Fire Clay Bodies, 266; The Fine Grinding of Refractory Materials before Testing, 534; Modified Load Test for Fire Brick, 498.

Fire Clay—The Burning Properties of Some American Refractory Clays, 246; The Effect of the Size of Grog in Fire Clay Bodies, 266; The Fine Grinding of Refractory Materials before Testing, 534; The Relation between the Fusion Point and the Composition of Refractory Clays, 303.

Firing—Glass Tank Furnace Operation, 331; Heat Balance of a Continuous Tunnel Kiln, 216; A New Principle in Temperature Measurement, 260; The Properties of American Bond Clays, 601; Relation of Fusion Point of Ash to Availability of Coal for Burning Ceramic Ware, 488.

Flocculation—The Use of Sulphuric Acid in the Sedimentation of Kaolins, 130.

Floor Tile—The Manufacture of Promenade Tile, 361; The Effect of Pressure in the Forming of Dust Pressed Tile, 94.

Florida Kaolin—Temperature, Porosity, Volume Changes of Some Porcelain Bodies, 636; The Use of Sulphuric Acid in the Sedimentation of Kaolins, 133.

Frink R. L.—Chemical Condition of Manganese in Glass When Used as a Decolorizer, 370; Glass Tank Furnace Operation, 331.

Fulton, C. E.—The Relation between the Fusion Point and the Composition of Refractory Clays, 303.

Fusibility—Control of Fusibility in Fritted Glazes, 642; Latent Heats of Fusion of Lime and Magnesia, 195; The Relation between the Fusion Point and Composition of Refractory Clays, 303; The Fine Grinding of Refractory Materials before Testing, 534.

Fusing Point of Coal Ash—Relation of Fusing Point of Ash to Availability of Coal for Burning Ceramic Ware, 488.

Georgia Kaolin—The Relation of Salt to Clay in the Purification of Clays, 460; Temperature, Porosity, Volume Changes of Some Porcelain Bodies, 636; The Use of Sulphuric Acid in the Sedimentation of Kaolins, 130.

Glass—Chemical Conditions of Manganese in Glass When Used as a Decolorizer, 370; Glass Tank Furnace Operation, 331; Principles Controlling the Formation of Bubbles in Molten Glass, 201.

Glass Sands—Glass Sands, 160; Their Formation, 169.

Glazes—Causes for the Failure of Terra Cotta in the Wall, 593; Chrome Tin Colors at Cone 9, 378; Control of Fusibility in Fritted Glazes, 642; The Cost of Raw Lead Glazes, 659; The Crawling of Mat Glazes, 597; A Deformation Study of $BaO — Al_2O_3 — SiO_2$ Mixture, 457; A Deformation Study of $MgO_1 — Al_2O_3 — SiO_2$ Mixture, 453; The Effect of Porosity of the Body

and the Moisture Content of the Glazes in the Application of Mat Glazes, 428; Investigation of the Ternary System, Willemite, Tephroite Soda Glass, 674; Note on Over-Glaze Colors at Cones 6-7, 653, Pinholing and Peeling of Terra Cotta, 209; The Practical Application of Bristol Glazes, Compounded on the Eutectic Basis, 301; A Study of the Physical and Chemical Properties of the Three Compounds of Lead and Their Use in Raw Lead Glazes, 442; A Study of the Three Component Normative Systems in Raw Lead Glazes, 312.

Grenville—The Magnesite Deposits of the Grenville District, Quebec, 254.

Grog—The Effect of the Size of Grog in Fire Clay Bodies, 268.

Gross Almerode Clay—The Properties of American Bond Clays, 622.

Gum Arabic—To Prevent Pinholing and Peeling on Terra Cotta, 214.

Harrop, Carl B.—Heat Balance of a Continuous Tunnel Kiln, 216.

Harter, W. C.—A New Principle in Temperature Measurement, 260.

Hausmanite—Investigation of the Ternary System, Willemite, Tephroite, Soda Glass, 674.

Heat Balance—Heat Balance of a Continuous Tunnel Kiln, 216.

Heat Losses—Heat Balance of a Continuous Tunnel Kiln, 216.

Hewitt, L. C.—The Cost of Raw Lead Glazes, 659.

Hice, Richard R.—Relation of Fusing Point of Ash to Availability of Coal for Burning Ceramic Wares, 488.

Historical—The Development of Ceramic Decorative Processes, 449.

Howe, Raymond W.—Principles Controlling the Formation and Removal of Bubbles in Molten Glass, 201.

Humidity—Humidity, Its Control and Relation to the Drying of Clay Wares, 538.

Hunt, F. S.—The Effect of Porosity of the Body and the Moisture Content of the Glaze in the Application of Mat Glazes, 428.

Hydrodeik—Humidity, Its Control and Relation to the Drying of Clay Wares, 539; Use of in Determining Humidity, 217.

Hygrostat—Humidity, Its Control and Relation to the Drying of Clay Wares, 559, 562.

Kaolin—The Burning Properties of Some American Refractory Clays, 246; The Relation of Salt to Clay in the Purification of Clays, 460; A Study of Three Component Normative Systems in Raw Lead Glazes, 312; Temperature Porosity, Volume Changes in Some Porcelain Bodies, 636; Use of Sulphuric Acid in the Sedimentation of Kaolins, 130.

Keeler, R. B.—Recent Improvements in Methods of Terra Cotta Mold Making, 585.

Kentucky Ball Clay—American Clays for Floating Enamels, 339; The Relation of Salt to Clay in the Purification of Clays, 460; Properties of Some American Bond Clays, 616.

Kerr, E. G.—The Effect of Variation in Pressure and Moisture upon the Forming of Dust Pressed Tile, 409.

Kiln—Heat Balance of a Continuous Tunnel Kiln, 216; Relation of Fusing Point of Ash to Availability of Coal for Burning Ceramic Ware, 488.

Kirkpatrick, F. A.—The Effect of Size of Grog in Fire Clay Bodies, 268.

Klingenberg Clay—Properties of Some American Bond Clays, 607.

Latent Heat of Fusion—Latent Heats of Fusion of Lime and Magnesia, 195.

Lead Glazes—A Study of the Three Component Normative Systems in Raw Lead Glazes, 312.

Lime—Latent Heat of Fusion of Lime and Magnesia, 195.

Litharge—A Study of the Physical and Chemical Properties of Three Compounds of Lead and Their Use in Raw Lead Glazes, 442.

Load Test—Modified Load Test for Fire Brick, 498; Load Carrying Capacity of Clays, 250.

Local Sections—Presidential Address, 80.

Loomis, Geo. A.—Temperature, Porosity, Volume Changes of Some Porcelain Bodies, 636; The Properties of Some American Bond Clays, 616.

Magnesia—Latent Heats of Fusion of Lime and Magnesia, 195; A Deformation Study of $MgO - Al_2O_3 - SiO_2$ Mixture, 453.

Magnesite—The Magnesite Deposits of the Grenville District, Quebec, 254.

Manganese—Chemical Condition of Manganese in Glass When Used as a Decolorizer, 370.

Mat Glazes—The Cost of Raw Lead Glazes, 670; The Crawling of Mat Glazes, 597; The Effect of Porosity of the Body and the Moisture Content of the Glaze in the Application of Mat Glazes, 428; A Study of Three Component Normative Systems in Raw Lead Glazes, 316, 322, 325.

Marquardt Tubes—Production of Special Refractories—Marquardt Porcelain and Magnesium Aluminate, 397.

Melting Point—The Relation between the Fusion Point and the Composition of Refractory Clays, 303.

Membership—Presidential Address, 69.

Microscopic Examination—Enamel Surfaces under the Microscope, 146; Investigation of the Ternary System, Willemite, Tephroite, Soda Glass, 674.

Minton, R. H.—Chrome Tin Colors at Cone 9, 378.

Modulus of Rupture—The Effect of Size of Grog in Fire Clay Bodies, 268; The Properties of Some American Bond Clays, 601.

Molds—Recent Improvements in Methods of Terra Cotta Mold Making, 585; Molds for Marquardt Tubes, 397.

Montgomery, R. J.—The Fine Grinding of Refractory Materials before Testing, 534; The Relation between Fusion Point and the Composition of Refractory Clays, 303.

Morgan, F. A.—A Study of the Physical and Chemical Properties of Three Compounds of Lead and Their Use in Raw Lead Glazes, 442.

Morris, George D.—Wet Clay Elevator, 484; Flow of Clay through Hollow Ware Dies, 479.

Mount Savage Flint Clay—The Burning Properties of Some American Refractory Clays, 246.

Mount Savage Plastic Fire Clay—The Burning Properties of Some American Refractory Clays, 246.

Norm Composition—A Study of the Three Component Normative Systems in Raw Lead Glazes, 312.

North Carolina Kaolin—Temperature, Porosity Volume Changes of Some Porcelain Bodies, 636; Use of Sulphuric Acid in the Sedimentation of Kaolin, 133.

Northrup—A New Principle in Temperature Measurement, 261.

Orthoclase—A Study of Raw Lead Glazes, 312.

Paving Brick—Paving Brick from Blast Furnace Slag, 507.

Peeling—Pinholing and Peeling on Terra Cotta, 209.

Pence, Forrest K.—Effect of Variation of Pressure in the Forming of Dust Pressed Tile, 94.

Pinholing—Pinholing and Peeling of Terra Cotta, 209.

Plaster of Paris—An Instrument for measuring Plasticity of Plaster of Paris, 523; Measurement of the Time of Set of Calcined Gypsum, 573; Recent Improvements in Methods of Terra Cotta Mold Making, 585.

Plasticity—Flow of Clays through Hollow Ware Dies, 479; An Instrument for Measuring Plasticity, 523; The Properties of Some American Bond Clays, 601.

Porcelain—The Development of Ceramic Decorative Processes, 449; Temperature, Porosity, Volume Changes of Some Porcelain Bodies, 636; Note on the Production of Special Refractories—Marquardt Porcelain and Magnesium Aluminate, 397.

Porosity—The Burning Properties of Some American Refractory Clays, 246; The Effect of Size of Grog in Fire Clay Bodies, 268; Temperature, Porosity, Volume Changes of Some Porcelain Bodies, 636; The Effect of Porosity of the Body and the Moisture Content of the Glaze in the Application of Mat Glazes, 428; The Effect of Variation in Pressure and Moisture Upon the Forming of Dust Pressed Tile, 409; Effect of Variation of Pressure in the Forming of Dust Pressed Tile, 94; Volume Changes of Some Commercial Silica Bricks on Heating, 83.

Poste, Emerson P.—Enamel Surfaces Under the Microscope, 146.

Potato—Use of Potato in the Fining of Glass, 206

Potentiometer—A New Principle in Temperature Measurement, 260.

Pottery—Apatite, a Substitute for Bone Ash, 125; The Development of Ceramic Decorative Processes, 449; Humidity, Its Control and Relation to the Drying of Clay Wares, 538; Measurement of the Time of Set of Calcined Gypsum, 573; The Use of Sulphuric Acid in the Sedimentation of Kaolins, 130.

Presidential Address—69.

Pressure—Flow of Clays Through Hollow Ware Dies, 479; Effect of Variation of Pressure in the Forming of Dust Pressed Tile, 94; Effect of Variation in Pressure and Moisture Upon the Forming of Dust Pressed Tile, 409.

Promenade—The Manufacture of Promenade Tile, 361.

Psychrostat—Humidity, Its Control and Relation to the Drying of Clay Wares, 548.

Pyrometer—A New Principle in Temperature Measurement, 260.

Pyrometer Tubes—Note on the Production of Special Refractories—Marquardt Porcelain and Magnesium Aluminate, 397.

Pyrovolter—A New Principle in Temperature Measurement, 261.

Quartz—Glass Sands, 160; Volume Changes of Some Commercial Silica Bricks on Heating, 83.

Quartzite—Glass Sands, 173; Volume Changes of Some Commercial Silica Bricks on Heating, 91.

Quebec—The Magnesite Deposits of the Grenville District, Quebec, 254.

Quenching Treatment—The Effect of the Size of Grog in Fire Clay Bodies, 286.

Radiation—Heat Balance of a Continuous Tunnel Kiln, 216.

Rattler Test—Paving Brick from Blast Furnace Slag, 507.

Red Lead—A Study of the Physical and Chemical Properties of Three Compounds of Lead and Their Use in Raw Lead Glazes, 442.

Refining of Glass—Principles Controlling the Formation of Bubbles In Molten Glass, 201.

Refractories—The Burning Properties of Some American Refractory Clays, 246; The Fine Grinding of Refractory Materials Before Testing, 534; The Magnesite Deposits of the Grenville District, Quebec, 254; Modified Load Test for Fire Brick, 498; Properties of Some American Bond Clays, 601; The Relation Between the Fusion Point and the Composition of Refractory Clays, 303; Note on the Production of Special Refractories — Marquardt Porcelain and Magnesium Aluminate, 397. Volume Changes of Some Commercial Silica Bricks on Heating, 83.

Refining of Enamels—Enamel Surfaces Under the Microscope, 146.

Rhead, Frederick H.—The Development of Ceramic Decorative Processes, 449.

Rhodonite—Investigation of the Ternary System, Willemite, Tephroite, Soda Glass, 674.

Riddle, F. H.—Advantages of Clay Storage and the Description of a Successful Installation, 102; Production of Special Refractories—Marquardt Porcelains and Magnesium Aluminate, 397.

Riley, R. J.—Control of Fusibility in Fritted Glazes, 642.

Ross, Donald W.—Volume Changes of Some Commercial Silica Bricks on Heating, 83.

Saunders, Mary E.—The Crawling of Mat Glazes, 597.

Schurecht, H. G.—The Burning Properties of Some American Refractory Clays, 246; The Relation of Salt to Clay in the Purification of Clays, 460; The Use of Sulphuric Acid in the Sedimentation of Kaolins, 130.

Seeds in Glass—Principles Controlling the Formation and Removal of Bubbles in Molten Glass, 201.

Settling—American Clays for Floating Enamels, 339.

Sewer Pipe—Advantages of Clay Storage and the Description of a Successful Installation, 102; Flow of Clay Through Hollow Ware Dies, 479.

Shaw, J. B.—American Clays for Floating Enamels, 339; Modified Load Test for Fire Brick, 498. Paving Brick from Blast Furnace Slag, 507.

Shrinkage—Effect of Variation of Pressure in the Forming of Dust Pressed Tile, 94; The Effect of Variation in Pressure and Moisture upon the Forming of Dust Pressed Tile, 409.

Silica Brick—Volume Changes of Some Commercial Silica Bricks on Heating, 83.

Slag Brick—Paving Brick from Blast Furnace Slag, 507.

Slaking, Rate of—The Properties of Some American Bond Clays, 601.

Sodium Carbonate—Use of, in the Purification of Clays, 474.

Sodium Hydroxide—Use of, in the Purification of Clays, 476.

Sodium Silicate—Use of, in the Purification of Clays, 472.

Specific Gravity—Volume Changes of Some Commercial Silica Bricks on Heating, 83.

Spinel—Production of Special Refractories—Marquardt Porcelain and Magnesium Aluminate, 397.

Stains—Chrome Tin Glazes at Cone 9, 378; Note on Overglaze Colors at Cones 6-7, 653.

Staley, Homer F.—Control of Fusibility in Fritted Glazes, 642; The Cost of Raw Lead Glazes, 659.

Student Branches—Presidential Address, 80.

Sulphuric Acid—The Use of Sulphuric Acid in the Sedimentation of Kaolins, 130.

Sulphuring—Pinholing and Peeling on Terra Cotta, 213.
Tank Furnace—Glass Tank Furnace Operation, 331.
Tennessee Ball Clay—American Clays for Floating Enamels, 339.
Tephroite—Investigation of the Ternary System, Willemite, Tephroite, Soda Glass, 674.
Terra Cotta—Causes for the Failure of Terra Cotta in the Wall, 593; Note on Overglaze Colors at Cones 6-7, 653; Pinholing and Peeling of Terra Cotta, 209; Recent Improvements in Methods of Terra Cotta Mold Making, 585.
Testing—The Fine Grinding of Refractory Materials Before Testing, 534; Heat Balance of a Continuous Tunnel Kiln, 216; An Instrument for Measuring Plasticity, 523; Measurement of the Time of Set of Calcined Gypsum, 573; Modified Load Test for Fire Brick, 498; A New Principle in Temperature Measurement, 260; Paving Brick from Blast Furnace Slag, 507; The Properties of Some American Bond Clays, 601; The Relation of Fusing Point of Ash to Availability of Coal for Burning Ceramic Wares, 488; Tests on Slag Brick, 520.
Tiles—Chrome Tin Glazes at Cone 9, 378; The Effect of Porosity of the Body and the Moisture Content of the Glaze in the Application of Mat Glazes, 428; The Effect of Variation in Pressure and Moisture Upon the Forming of Dust Pressed Tile, 409; Effect of Variation of Pressure in the Forming of Dust Pressed Tile, 94; The Manufacture of Promenade Tile, 361.
Time of Set—Measurement of the Time of Set of Calcined Gypsum, 573.
Tin—Chrome Tin Glazes at Cone 9, 378.
Tridymite—Volume Changes of Some Commercial Silica Bricks on Heating, 83.
Turbo—Humidity, Its Control and Relation to the Drying of Clay Wares, 541.
Valendar Clay—American Clays for Floating Enamels, 339.
Viscosimeter—New Viscosimeter for Testing American Clays for Floating Enamels, 339; An Instrument for Measuring Plasticity, 523.
Viscosity—American Clays for Floating Enamels, 339; Determination of, in the Purification of Clays, 472; Principles Controlling the Formation and Removal of Bubbles in Molten Glass, 201; Viscosity of Raw Lead Glazes, 446.
Walker, F. W. Jr.—The Effect of Variation in Pressure and Moisture upon the Forming of Dust Pressed Tile, 409.
Wall Tile—Effect of Pressure in the Forming of Dust Pressed Tile, 94; The Effect of Porosity of the Body and the Moisture Content of the Glaze in the Application of Mat Glazes, 428; the

Effect of Variation in Pressure and Moisture upon the Forming of Dust Pressed Tile, 409.

Washburn, Edward W.—Latent Heats of Fusion of Lime and Magnesia, 195.

Washing—Preparation of Glass Sands, 187.

Water Content—The Effect of Variation in Pressure and Moisture upon the Forming of Dust Pressed Tile, 409.

Watts, Arthur S.—A Deformation Study of $BaO - Al_2O_3 - SiO_2$ Mixture, 457; A Deformation Study of $MgO - Al_2O_3 - SiO_2$ Mixture, 453; The Practical Application of Bristol Glazes Compounded on the Eutectic Basis, 301.

Weathering—Advantages of Clay Storage and the Description of a Successful Installation, 102.

White Lead—A Study of the Physical and Chemical Properties of Three Compounds of Lead and Their Use in Raw Lead Glaze, 442.

Whitford, Wm. G.—A Study of Three Component Normative Systems in Raw Lead Glazes, 312.

Willemite—Investigation of the Ternary System, Willemite, Tephroite, Soda Glass, 674.

Wilson, Hewitt—Note on Overglaze Colors at Cones 6-7, 653; Pinholing and Peeling of Terra Cotta, 209.

Wilson, M. E.—The Magnesite Deposits of the Grenville District, Quebec, 254.

Wollastonite—A Study of Three Component Normative Systems in Raw Lead Glazes, 319.

Zinc Oxide in Glazes—The Practical Application of Bristol Glazes Compounded on the Eutetic Bases, 301; A Study of Raw Lead Glazes, 322.